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Annual Report

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[Proc. Roy. Soc. Victoria, 57 (N.S.), Pts. I.-II., 1945.]

Art I.—*The Geology of Phillip Island.*

By A. B. EDWARDS, D.Sc.

[Read 13th July, 1944; issued separately 10th December, 1945.]

Abstract.

Phillip Island, which lies across the mouth of Western Port Bay, consists of a large central island, to which is tied a number of smaller islands at both its south-eastern and south-western extremities. It represents the south-eastern interfluve of the river that was drowned to form Western Port Bay. The land slopes gently northwards, and there are few permanent streams. High cliffs occur along the exposed southern coast, while the low northern coastline, in the shelter of Western Port Bay, is prograding. The island consists essentially of a number of flows of Tertiary Older Volcanic basalts, intercalated with thick beds of ochreous red tuff and agglomerate, and overlying Jurassic and Palaeozoic sediments and Palaeozoic granites.

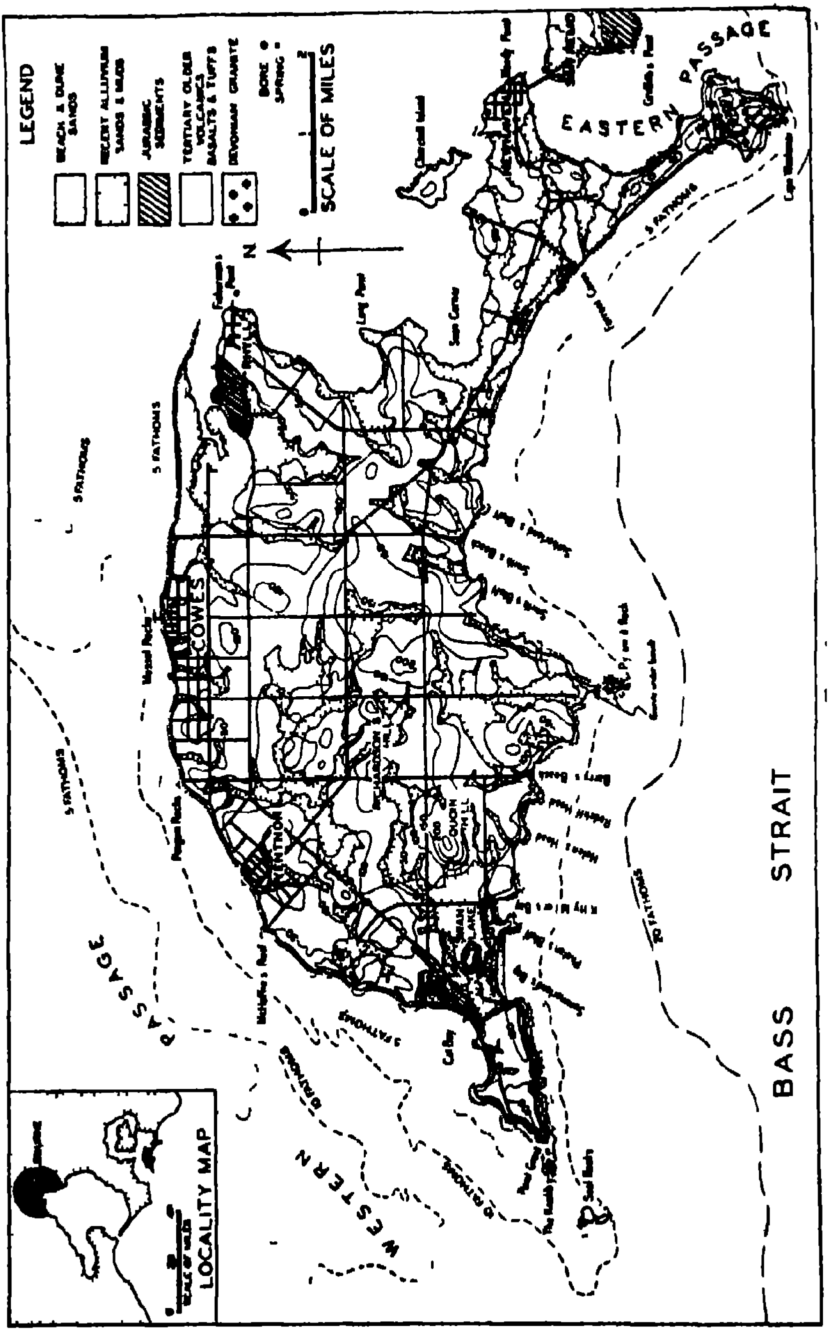
Introduction.

Phillip Island, which lies across the mouth of Western Port Bay, is 13 miles long and 5½ miles wide at its widest point. It has an area of about 60 square miles. On the eastern side it is separated from the San Remo Peninsula by the narrow Eastern Passage, which is from ¼ to ¾ of a mile wide, and has a maximum depth of about 30 feet. On the western side it is separated from the Mornington Peninsula by the Western Passage, which is from 2½ to 6 miles wide, and has a maximum depth of 90 feet. These two channels separating the island from the mainland are the drowned valleys of streams which were either overdeepened during a low sea-level period of the Pleistocene Ice Age or submerged as a result of subsidence during the Quaternary. The island represents the southern interfluve of the old Western Port River. The tidal range at Cowes, on the northern coast of the island, varies from 7½ feet at neap tides to 12 feet at spring tides, and the tidal race through the Passages develops a maximum velocity of 6 miles an hour.

COMPOSITE STRUCTURE.

As shown in fig. 1, Phillip Island is a composite island. It consists of a large central island, to which is tied a number of smaller islands.

The narrow south-western extremity of the present island consists of two small tied islands, here called Phelan's Island and Summerland's Island, and The Knobby. Phelan's Island and Summerland's Island are joined to the main island by a Y-shaped


LEGEND
BEACH & DUNE SANDS
RECENT ALLUVIUM SANDS & MUDS
JURASSIC SEDIMENTS
TERTIARY OLDER VOLCANICS BASALTS & TUFFS
DEVONIAN GRANITE
BORE
SPRING
SCALE OF MILES
0
1
2
N
EASTERN PASSAGE
WESTERN PASSAGE
BASS STRAIT
COWES
VENTNOR
SWAN LAKE
5 FATHOMS
10 FATHOMS
LOCALITY MAP
SCALE OF MILES

tombolo which encloses the partly silted-up fresh-water lagoon of Swan Lake The Knobby is connected to Summerland's Island by a storm-wave platform that is covered at high tide (Pl I, fig 1) About ½ mile to sea, south-west from the Knobby, is a further small island, Seal Rocks (Pl I, fig 1) The submarine contours show that it is an integral member of this group of small islands (fig 1) They are all composed of a series of basalt flows from 20 to 30 feet thick, separated by thin red beds of tuff or weathered basalt (flow tops) along which erosion is concentrated The lava-flows lie almost horizontal, but the surface of Summerland's Island slopes evenly to the north-west This series of islands is part of the ridge forming the south-eastern interfluve of the old Western Port River, and the passages between them represent the valleys of small streams tributary to this river The valleys between Phelan's Island, Summerland's Island, and the main island were first drowned, and then silted up, following the growth of bars across both ends of the channel The valley between The Knobby and Summerland's Island was left as a low level tract more subject to wave erosion than the higher land to the north-east and south-west Erosion was concentrated along a red band between the tide levels

The valley between Seal Rocks and The Knobby is too deeply drowned to permit the growth of spits in such exposed water

The narrow south-eastern extremity of Phillip Island also consists of a group of small islands tied to one another and to the main island The most prominent of these tied islands is that formed by the Cape Woolamai granite stock which is linked to the main island by a tie-bar ½ mile wide, carrying sand dunes over 100 feet high (Hills, 1940, p 229) The inner tied islands are rounded tops of low basaltic hills that rise only 50 feet above sea-level, and represent the higher land between a series of small valleys, some of which were tributary to the Eastern Passage, and some to the drowned Western Port river system

Topography.

The island has a gently undulating surface with a general slope to the north, so that whereas the cliffs along the southern coast rise to heights of 150 feet, those along the northern coast are only about 20 feet high The highest point of the island, apart from Cape Woolamai (300 feet), is Quoin Hill (250 feet), a volcanic plug about 1 mile north-east of Swan Lake Only four other points, Black Hill on the Ventnor-Knobby road, Richardson Hill in the centre of the island the adjacent hill in allotment 54 and the hill to the south-east of Quoin Hill rise to 200 feet above sea level A water parting extends from Quoin Hill to Rhyll

In the interior of the island, the valleys are shallow swampy depressions trending chiefly to the north or north-west (fig. 1). Near the coast, the valleys become more pronounced, and the valley slopes are sometimes steep, particularly along the south coast. The only permanent stream, the Native Dog Creek, is short and flows into Bass Strait between Helen's Head and Red-cliff Head, through a gorge about 150 feet deep.

WATER SUPPLY.

Water supply is a serious problem on the island. The rainfall is about 30 inches a year, distributed as shown in Table I.

TABLE 1.—AVERAGE MONTHLY RAINFALL.

	Points.
January	194
February	154
March	247
April	258
May	292
June	320
July	280
August	287
September	287
October	262
November	218
December	206

Potable water is available from shallow wells along the back-shore near Cowes township, and most of the local supply is pumped from these wells. The water lies at depths of from 5 to 10 feet, and the water level fluctuates with the tides, owing to the banking up of the seepage at high tides. The water is hard and somewhat saline as is indicated by the analyses Nos. 1 and 2, in Table 2, which were supplied by the courtesy of the Shire Secretary.

In the interior of the island, water is obtained from a number of wells and bores between 50 and 100 feet deep. The water is suitable for stock, but too mineralised for human consumption (Table 2, No. 4). It seeps down the columnar joints of the basalts and accumulates at the base of the basalt flows where they overlie more or less impervious tuff beds.

Springs occur at several localities. A spring of fresh water occurs on the northern side of the high sand dunes, in the reserve between allotments 148 and 151, in the narrow neck of land south of Swan Corner. The dunes overlie a thick bed of tuff, the surface of which slopes to the north. Rain water apparently percolates inland along this surface. Springs of mineralised water occur on the northern side of the Cape Woolamai granite, where the water has penetrated joint planes in the granite, and also close to Cape Woolamai itself (Blandowski, 1857, p. 56). Summerland's House in the south-west of the island obtains much of its water from a spring that issues on the northern side of the tie-bar joining Summerland's Island to the main island. Mr. V. G. Anderson has kindly supplied an analysis of the water of this spring (Table 2, No. 3).

TABLE 2.—ANALYSIS OF WELL AND SPRING WATER, PHILLIP ISLAND.
(mg. per litre.)

	1	2	3	4
Ca	n.d.	n.d.	113	69
Mg	n.d	n.d.	30	133
Na, K	70	45	136	819
Cl	100	65	234	1249
SO_4	n.d.	n.d.	18	65
HCO_3	n.d.	n.d.	478	355
NO_3	04	.86	.9	
SiO_2	n d.	n.d.	14	
Al_2O_3	n.d	n d	4	
Fe_2O_3	n.d.	n.d.		11
Total Solids	470	340	1027.9	2701

1. Mathew's Well, Cowes, March, 1937.
2. University Camp Well, Cowes, March, 1937.
3. Water from Summerland's Spring, February, 1934.
4. Water at 117 ft., and rising to 100 ft., in Bore 8, allot. 13. (Rec. Boring Oper., 1926, p. 60).

The Coastlines.

The northern and southern coastlines present a striking contrast, partly owing to the marked difference in the strength of wave attack to which they are subjected, and partly owing to the northerly slope of the surface of the island, which greatly reduces the cliff height on the northern side.

THE SOUTHERN COASTLINE.

The southern coastline is exposed to the full violence of south-westerly gales sweeping across Bass Strait. It forms two large concave arcs, one on either side of the promontory leading out to Pyramid Rock, and consists of three sections of unequal length.

The western section, which is the longest, extends from The Knobby to near Sutherland's Bluff, where only a narrow neck of land, ¼ mile wide, separates Swan Corner from Bass Strait. This section consists of steep to sheer cliffs, 50 to 150 feet high (Pl. II., fig. 1), broken at irregular intervals by short stretches of sandy beach. The cliffs are cut in basalt and in thick beds of tuff and agglomerate. The steeper cliffs are cut in the basalts and as many as five successive flows of basalt, more or less horizontal, are exposed in the cliff faces, and stormwave platforms at their bases (Pl. I., fig. 1). In places, the uppermost lava-flow has been so eroded as to form an amphitheatre-like depression in the cliff tops (Pl. I., fig. 6). These depressions are not related to drainage lines, and it is difficult to explain their origin.

The almost vertical black cliffs in the basalt contrast strongly with the higher, less steep cliffs in the bright red-brown tuffs and agglomerate The tuffs and agglomerates only occur at intervals—namely, at Phelan's Bluff, Redcliff Head, Smith's Bluff, Sutherland's Bluff, and at Forrest Caves and the unnamed bluff west of it At each locality the tuff or agglomerate overlies more resistant basalt flows, which, at Phelan's Bluff and Redcliff Head, form the base of the cliffs for 10 to 20 feet above high tide level At Phelan's Bluff, the tuff has been cut back so far that it is now beyond the reach of all but the largest waves and is faced with a boulder beach The resulting double storm-wave platform at first sight suggests a recent coastal emergence of 14 feet (Pl II, fig 3)

All the headlands, and any straight sections of cliffs are fronted by storm wave platforms (Edwards, 1941) These become narrow on the sides of the headlands, and in the smaller inlets they give place to steep boulder beaches, while in the larger inlets they give place to sandy beaches The platforms are covered at high tide They tend to be widest where the cliffs are relatively low, and grow narrower as the cliff height increases The widest platforms are in the vicinity of Smith's Beach, where they are up to 300 feet wide The surface of a platform frequently coincides with the top of a horizontal basalt flow (Pl I, figs 3 and 4) The tops of the flows are commonly marked by a red band of decomposed rock or tuff from a few inches to a foot or more in thickness The red band is less resistant to wave attack than the overlying columnar basalt which is readily sapped The surface of the resulting platform is generally level (Pl I fig 4), but it sometimes shows an abrupt "step-up" in level (Pl I, figs 1, 4) This results from the columnar structure of the basalt flow above the red band The basalt generally consists of an upper layer of columns with closely spaced horizontal joints and a base of broad stumpy columns with few horizontal joints (Pl I, fig 3) The junction of the two sets is a plane of weakness and the wave attack may be more effective in eroding the upper layer of closely jointed columns than in sapping the whole thickness of the flow Where this has happened, the platform "steps up" the height of the lower columns (Pl I, fig 4) At an advanced stage of the erosion of such a "step up," only isolated individual columns remain, rather like bollards, on the surface of the platforms (Pl I, fig 5)

Residuals of the upper flow sometimes remain as rock stacks on the storm-wave platforms (Pl I, figs 2 6) Pyramid Rock at the midpoint of this western section of the southern coast, is a rock stack of residual basalt columns, surrounded by a "skirt" of scree on an irregular platform of pinkish granite (Pl II, figs 1, 2) The granite platform is separated from the main island by a narrow channel formed along a master joint

The surfaces of the storm-wave platforms are relatively smooth where they retain a veneer of the red band (Pl I, fig 4) Where the red band has been stripped completely from the platform, its surface is usually grooved by a network of gutterways which follow the columnar joints of the basalt The basalt adjacent to the joints shows apparent pseudo-flow structure parallel to the jointing This is an effect of directed attrition by sand and similar fine material swept along the gutterways

Some platforms show sloping surfaces and abrupt changes in level where they are cut in gently dipping basalt flows of different hardness, or where, as at the eastern end of Smith's Beach, they intersect a sloping bed of silicified gravel intercalated with the basalts Pot holes, containing more or less spherical pebbles, are sometimes present

Some platforms show a well-defined "rampart" at their seaward edge, but others remain uniformly level right to the edge (Pl I, figs 1, 2) The seaward face or 'nip" (Edwards 1941) is steep to vertical, though sometimes bevelled at the top

The line of cliffs is broken at Summerland s Bay and at Kitty Miller's Bay by stretches of beach, backed by sand dunes up to 50 feet high These cap the tie bars joining Summerland's Island and Phelan s Island to the main island At the head of Kitty Miller s Bay, the dunes have buried a boulder beach rising for 15 to 20 feet above high-tide level

Small bay-head beaches occur in the embayments near Helen s Head, at the mouth of Native Dog Creek (Barry's Beach) and at a few other points The cliff line is otherwise unbroken as far as Smith s Beach, where there is a long stretch of beach with dunes accumulating on sloping cliffs of weathered basalt overlain by laterised tuffs East of this point the proportion of beach to cliffs and storm-wave platforms increases, until beyond Forrest Caves the transition to the second section of the coastline is complete

The second section of the southern coastline extends from Forrest Caves to the beginning of the granite cliffs near Cape Woolamai It consists of a sandy beach with occasional outcrops of basalt in the shore platform and is backed by cliffs cut in sand dunes that rise to 100 feet above sea level and form the tie bar connecting the tied islands to the main island The dunes are migrating inland Forrest Caves are two small caves about 10 feet high cut in the face of a storm-wave platform of laterised tuff Their roofs have partly collapsed, and they are submerged at high tide

The third and most rugged section of the coast consists of the granite cliffs in the vicinity of Cape Woolamai The tilt of the surface of the granitic stock at 5° to the north (Edwards 1942) results in an increase of cliff height southwards, until at Cape Woolamai the cliffs are about 250 feet high. The cliffs along the south-western side of the tied island, facing the strongest wave attack (Pl. II., figs. 5, 6) present a bolder and more rugged aspect than those on the south-eastern side (Pl. II., fig. 4). Erosion has driven deeply along the joint planes of the granite, forming gorge-like indentations (Pl. II., fig. 6), sometimes fronted by jagged pyramidal rock stacks, cut off from the cliffs at high tide (Pl. II., fig. 5). Storm-tossed boulders are found along even the highest cliff tops. On the south-eastern side of the tied island the cliffs are very steep, but the headlands are widely spaced between smoothly curved embayments, and the shallow bayheads are backed by a narrow, shelving beach (Pl. II., fig. 4). There are no storm-wave platforms along this section of the coast, presumably because the rocks are too hard to permit any distinctive low-tide erosion (Edwards, 1941).

Proceeding northwards along the Eastern Passage, the height of the cliffs decreases, until a little north of the old granite quarry and its jetty they give place to smoothly rounded sand dunes (Pl. II., fig. 7), which are migrating northwards along the tie-bar, and occasional outcrops of basalt at sea-level. Still further north, the coast is protected from all wave attack, and the high-tide level is marked by a slight nip, with trees and grasses coming down almost to high water level.

THE NORTHERN COASTLINE.

The northern coastline is largely screened from wave attack by French Island and by the easterly extension of the Mornington Peninsula to Sandy Point. These obstacles prevent the development of large waves under the influence of northerly winds, even during gales. The composite tie-bars and islands at the eastern end of Phillip Island effectively shelter the island from south-easterly winds, and prevent rollers from passing through the Eastern Passage. The broad Western Passage, however, faces directly towards the south-west, and affords an easy passage for waves and rollers coming from this direction. Where these waves impinge on the northern coastline in the vicinity of The Knobby and along the north-western side of Summerland's Island, they have cut steep cliffs in the basalt comparable with those along the southern coast. Further from the mouth of Western Passage the strength of the wave action is reduced by the shallow reefs and banks in the Passage, and the land surface becomes lower. A sandy beach begins at Cat Bay (Pl. III., fig. 3), and extends with only minor breaks almost to Rhyll. Beach cusps are often prominent along the section between Cat Bay and McHaffie's Reef. In the sheltered part of Cat Bay, a sand ridge has formed in front of the cliffs, from which it is separated by a shallow swale (Pl. III., fig. 3), and high dunes have formed along the tie-bar joining Summerland's Island to the main island. Cliffs up to 50 feet high persist from north of Cat Bay jetty to McHaffie's Reef. They are cut chiefly in red tuff or decomposed basalt. The tuff overlies the basalt. Fresh basalt is exposed only below high tide mark at the headlands. Sand has accumulated on top of the cliffs, and is migrating inland. Wind erosion has exposed numerous calcareous concretions and root moulds.

At McHaffie's Reef, vertical cliffs up to 50 feet high occur in sloping beds of red tuff, overlying weathered basalt (Pl. III., fig. 2), and a small storm-wave platform has been cut in the tuff on the northern side of the headland (Pl. III., fig. 1).

North of McHaffie's Reef, the coastline trends about 30°N. of E., so that the south-west waves set obliquely to the shore. Longshore drifting of the sand tends to silt up the creek mouths, and the cliffs, which are reduced to 25 feet in height, are faced by one or two sand ridges along the backshore. Low vertical cliffs recur at Penguin Point, where beds of red tuff come down to sea-level. The northerly dip of these beds causes them to strike across the line of the beach.

Beyond Penguin Point, the coastline trends east. The low sandy cliffs continue behind a widening stretch of sloping sandy beach, with a broad shore platform cut in basalt or tuff showing at low tide. The coast is prograding and the shoreline has advanced about 100 yards from the cliff. According to information received from residents, the advance is about 1 yard a year. The back shore consists of one or more ridges of fixed sand, separated from the old cliff line by a broad swale. The beach slopes steeply between high and low water marks, and at low tide there is a strong issue of seepages a few feet above the low water along almost the whole length of the beach. Three small headlands of red tuff, the Mussel Rocks, break the beach line close to Cowes pier.

East of Cowes pier the waves produced by both south-westerly and north-westerly winds combine to set up long-shore drift to the east, with little or no counter tendency from the shallow and sheltered eastern part of Western Port Bay. The eastward drift has caused the formation of a spit, which is now 3½ miles long and is still building out eastwards (Pl. III., fig. 4). This spit has grown across the mouth of a large bay, silted up into a salt marsh, part of which has been drained (Pl. III., fig. 7). The original coastline is marked by a line of cliffs continuous with the present cliffs facing the Nits near Rhyll, and extending almost to Cowes. The older part of the spit is covered by dunes which carry thick tea-tree scrub, but the eastern end is a bare sand bar (Pl. III., fig. 4). The tip of the spit is exposed only at low tide, for a distance of about 1,000 yards, and is becoming compound. The part of the bay still open behind the spit is largely mangrove swamp.

Prior to the growth of the spit steep cliffs 50 feet high were cut in Jurassic sediments and Tertiary basalts that outcrop west of Rhyll (Pl III fig 5) Where protected by the spit these cliffs are weathering to form gentle slopes but at the north east corner of the island where the coastline turns southwards they are exposed to wave attack and are nearly vertical The basalt of which they are composed is largely decomposed above high water mark

South of Fisherman s Point at Rhyll where the coast is protected from all but occasional small waves progradation is taking place and a sandy flat extends out some hundreds of yards from the old cliff line which is now rounded and grassed to a nip about 4 feet high fronted by a beach a few yards wide (Pl III fig 8) Bores at intervals up to 175 feet out to sea from the jetty show that the original surface of the sea floor has been buried beneath more than 50 feet of muds The head of the bay between Fisherman s Point and Long Point is partly silted up and the silting up process extends around Long Point into Swan Corner (Pl III fig 6) which is sheltered by Churchill Island At low tide Swan Corner becomes a mud flat with a shallow channel in the centre but an old cliff line is evidence of past wave attacks At Newhaven beyond the shelter of Churchill Island cliffs develop again in decomposed basalt and similar cliffs occur on the north eastern side of Churchill Island

General Geology

Phillip Island consists essentially of a number of flows of Tertiary Older Volcanic basalts intercalated with beds of red tuff and agglomerate and overlying Jurassic and Palaeozoic sediments and Palaeozoic granites Outcrops are largely obscured by soil and alluvium and near the coast by sand dunes

The earliest description of the geology is given by Blandowski (1857) in a report on his journey from King s Station to Bass River Phillip and French Islands The Woolamai granite has been described by McInerny (1929) but apart from this other geologists have made only passing reference to the island The south eastern corner of Phillip Island was mapped by Stirling in 1892 as part of Quarter Sheet 76 SW and during the present work an incomplete manuscript map of the island by Stanley Hunter was made available to the author by the courtesy of Mr W Baragwanath Director of the Geological Survey of Victoria

PALAEOZOIC SEDIMENTS

Although not outcropping on Phillip Island Palaeozoic sediments have been proved in situ in deep bores at Cowes (Bore No 2) at a depth of 306 feet below sea level and at Rhyll (Bore No 1) at a depth of 459 feet Sandstones presumably of

Palaeozoic age were encountered at a depth of 216 feet in Bore No 8 in allotment 143 Xenoliths of little altered rock several feet across occur in the granite outcrop opposite Pyramid Rock

The Palaeozoic sediments must occur in the sea bed in the vicinity of Cape Woolamai because boulders of hornfels and indurated sandstone are found on the southern beaches in the vicinity of the granite stock and similar boulders are found along the south western cliffs of the granite area where they have been tossed up by storm waves It seems likely that these rocks form the sea bed over a considerable area between Cape Woolamai and Pyramid Rock

The sediments are probably of Ordovician age since Ordovician graptolites have been found in boulders of slate near Griffith's Point on the San Remo Peninsula (Hall 1904)

JURASSIC SEDIMENTS

As noted by Blandowski (1857) Jurassic strata outcrop in the north eastern corner of the island in the cliff section facing the Nits west of Rhyll township (fig 1) They extend inland for about ½ mile and then pass beneath alluvium and Tertiary basalts The cliff section is about 50 feet high and excellent exposures are afforded in quarries along the cliff face (Pl III fig 5) The sediments consist of felspathic grits and friable arkose with a few thin beds of grey and black mudstones The mudstones contain fragmentary plant remains such as *Alethopteris sp* and *Sphenopteris sp* sufficient to establish their Jurassic age

The beds dip southwards and show gentle fold undulations along the cliff face Blandowski concluded that these beds underlie the inlet to the north and estimated their thickness at between 400 and 500 feet This is borne out by Bore No 1 in allotment 17 which passed from Jurassic to Palaeozoic strata at a depth of 459 feet below sea level (Ann Rept Dept Mines for 1912 p 137) No other outcrop of Jurassic rocks is known on the island but the Cowes bore put down at sea level in the Recreation Reserve encountered a thickness of 120 feet of Jurassic strata beneath 186 feet of basalts and tuffs Bore No 7 at Newhaven reached the Jurassic at a depth of 294 feet in allotment 13 (fig 1)

TERTIARY SEDIMENTS

Thin beds of pre basaltic gravels derived from the adjacent granite occur in the cliffs facing Pyramid Rock and along the northern margin of the Cape Woolamai granite Post-basaltic gravels of a similar character cap the basalt flow facing Pyramid Rock and an inter basaltic gravel about 10 feet thick which has been converted to quartzite is found at the eastern end of Smith's Beach where it outcrops as a ridge in the storm wave platform Boulders of this quartzite are numerous along the adjacent beaches The outcrop is crescentic to the south and dips inwards, indicating that it was deposited in a north sloping valley in the underlying basalt

Red gravels up to 10 feet thick overlying decomposed basalt outcrop from beneath the dunes just north of Cat Bay jetty They resemble the Red Beds above Older Volcanic basalts at Stony Point and at Cornella Point on the western and eastern shores of Western Port

RECENT SEDIMENTS

Alluvium fills most of the shallow valleys on the island and dune sands are found at intervals along the coast especially along the tie bars Recent sands and gravels are developed where the sheltered portions of the coast are prograding

IGNEOUS ROCKS

AMPHIBOLITES

Numerous boulders of amphibolite have been washed up in the shingle and boulder beach along the western side of Kitty Miller's Bay (Phelan's Bluff) They may be derived from Pre Cambrian rocks offshore but it seems more probable that they are derived from the ballast of the Speke which was wrecked off this point in February 1906

GRANITES

Granites presumably of Devonian age outcrop in the south eastern extremity of the island at Cape Woolamai and at Pyramid Rock midway along the southern coast fig 1)

The Woolamai granite is a stock like body covering an area of about 4 square miles The eroded surface of the stock slopes at 5°N The stock was originally part of the Bass horst and owes its northward tilt to the fault movements that gave rise to the horst (Edwards 1942) Good exposures are limited to the cliffs The rock has been described by McInerny (1929) and its heavy minerals have been listed by Baker (1942) It is the most acid of analysed Victorian granites It consists of quartz microperthite and oligoclase and occasional flakes of biotite Some of the biotite is altered to chlorite which accounts for the intense green colour of the mica noted by Blandowski (1857 p 54) The microperthite contains much iron oxide dust which causes it to appear a pleasing pink in the hand specimen The rock is relatively coarse grained individual crystals averaging about 3 mm across It has a high crushing strength (27 100 lb per sq in)

The granite has been quarried for building purposes on the eastern side of the stock close to water level It is strongly jointed in the vicinity of the quarry, one set of master joints strikes N S and dips at 60°E another strikes E-W and dips at 30°S On the opposite side of the island this jointing has given rise to pyramidal rock stacks Along the south eastern part of the coast two sets of flat dipping joints one dipping east and the other west combine with nearly vertical joints to produce a columnar or blocky structure in the cliffs

Veins and segregations of aplite and pegmatite traverse the granite in places Crystals of reddish brown orthoclase an inch or more long are found in vughs in the pegmatites Xenoliths and segregations of basic minerals are generally absent

At its northern end the granite is overlain by thin beds of Tertiary gravels largely derived from the granite and by Tertiary basalts and Recent dunes

Granite outcrops at the base of Pyramid rock in the cliffs of the main island where it is overlain by thin grit beds and by columnar basalt This outcrop is finer grained than the Woolamai granite but is otherwise similar It contains xenoliths of Palaeozoic sediments ranging up to 3 feet across The larger xenoliths are practically undigested

TERTIARY VOLCANIC ROCKS

The Tertiary volcanic rocks consist of flows of basalt of thicknesses ranging from 15 ft to 90 ft intercalated with beds of tuff and agglomerate up to 150 feet thick The tuffaceous material is generally altered to red clay red ochre or laterite The relation of the volcanic rocks to the fault movements that have affected Western Port leaves no doubt that they belong to the Tertiary Older Volcanics and this is confirmed by the petrological character of the basalts

PYROCLASTIC ROCKS

The volume of pyroclastic rocks on Phillip Island appears to equal the volume of lava flows They are best exposed along the southern coast between Phelan s Bluff and Forrest Caves They form prominent red headlands They show rude stratification and at Redcliff Head Smith s Beach and Forrest Caves they dip inland at about 5°N The coarsest agglomerate contains angular fragments of decomposed shaly material several inches across embedded in red clay Massive agglomerates grade with decrease in the size of the fragments into beds of ochreous red clay such as have been found intercalated between the Older Volcanic basalts at Flinders and Korkuperrimul Creek (Jacobson and Scott 1937) In places as east of Forrest Caves the tuff is only partly ironstained and unstained grey clays are found with hardened red clay in the joints and bedding planes The soft grey clay contains about 40 per cent of gibbsite and halloy site soluble in sulphuric acid Where this parti-coloured tuff is subject to wave attack the grey clay is washed away leaving a coarsely honeycombed cliff face

At Smith's Beach, red tuff overlying deeply weathered basalt is completely lateritized.

Ochreous red tuff beds outcrop in the vicinity of McHaffie's Reef and at Penguin Rocks. At McHaffie's Reef, and for about 300 yards south of this headland, the tuffs form a gently domed structure which is exposed in section in the cliffs. Presumably these arched tuff beds are part of an old volcanic cone. Some of the tuff is closely spotted with areas of a white clay-like zeolitic substance, apparently halloysite.

At Penguin Rocks, red tuff beds occur which dip to the north, and form an abrupt low cliff crossing the beach almost at right angles. A quarter of a mile to the south-west what are apparently the same beds outcrop in the beach with a southerly dip. Between these two points the red beds can be observed in the cliff section, where they dip eastwards. Presumably these tuffs mark another centre of eruption.

Similar, but lateritized, red beds form the Mussel Rocks near Cowes Jetty and outcrop in the main street; shallow cuttings along the various roads across the island indicate that the tuffs are widespread. In most of the outcrops they can be seen to overlie basalt flows, but at Smith's Beach a basalt flow can be seen in section, filling a valley eroded in the tuffs.

LAVA FLOWS.

Flows of basalt extend over the greater part of the island, but with a few exceptions, such as Quoin Hill, exposures in the interior of the island are poor. The best exposures are along the southern coast between the Knobby and Summerland's Beach, and between Kitty Miller's Bay and Smith's Beach. Along these sections of the coast as many as five successive flows are exposed in section. The individual flows are from 15 to 90 feet thick.

At Pyramid Rock and at the northern end of the Woolamai granite mass, the basalts can be seen overlying the granite bedrock, but the bore records show that the base of the basalt series lies well below sea-level—near Newhaven it is between 200 and 290 feet below sea-level, while at Cowes it is about 180 feet below. It is probable, therefore, that the granitic outcrops, and the Jurassic outcrop west of Rhyll, represent hills rising above the general level of the pre-basaltic terrain.

The outcropping basalts are all closely similar. They are undersaturated olivine-basalts, chiefly of the Flinders type (Edwards, 1938). Samples from the two flows encountered in the Cowes bore are also of this type. The rock composing Quoin Hill is an olivine-basalt with titaniferous augite, and is of the Mooroodue type. Thin sections in the Geology Department collection include an olivine basalt of the Keilor type. The only other variant encountered is an olivine-basanite, from the bottom of the gorge near the mouth of Native Dog Creek. This rock is very closely allied to the characteristic monchiquites of the Older Volcanic series, except for an unusual richness in analcite.

Zeolites, chiefly gmelinite and chabazite, and sometimes aragonite, abound in the vesicles of some of the flows, particularly near their bases, especially in the vicinity of Smith's Bluff and Sutherland's Bluff.

The only prominent point of eruption is Quoin Hill, an almost conical plug which rises steeply to about 150 feet above the surrounding country. A flow appears to have issued from this centre on its west side.

The only chemical analysis of these basalts is that quoted by Skeats (1909) from Selwyn's Catalogue of Rock Specimens and Minerals in the National Museum, Melbourne, 1868. The analysis, which is a second-grade one, shows a general resemblance to analyses of the Flinders type of basalt but is not typical in that the MgO content of the analysed specimen is unusually high, and the CaO content is lower compared with most Victorian analyses.

DYKES.

Several light-coloured dykes of a mugearitic character have been intruded into the basalts in the storm-wave platform at Point Grant. They are up to 2 feet wide, and fill master joints in the basalt, sometimes projecting as low walls. They sometimes step sideways along joint planes, and then resume their main trend, until they split into several branches a few inches wide, each following a separate joint plane. Some movement has taken place since their intrusion, because one dyke was observed to be slightly faulted The dykes have chilled margins, with a somewhat coarser central part, showing flow banding. They consist essentially of parallel laths of felspar, too altered for precise determination. Much of it appears to be oligoclase. Ferromagnesian minerals, if originally present, were restricted to the groundmass, but the rock is too altered to reveal them.

Several similar dykes intrude the basalts in the shore platforms between Cat Bay jetty and McHaffie's Reef.

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Description of Plates.

PLATE I

FIG 1—The Knobby from Summerland's Island at low tide Seal Rocks in the distance

FIG 2—Storm wave platform with rock stack cut in horizontal basalt flows south coast Summerland's Island near the blow hole

FIG 3—Showing the columnar structure of the basalt overlying the 'red band' in which the storm wave platform is cut

FIG 4—Surface of a storm wave platform cut in a red band with a 'step up' in the left middle distance

FIG 5—Residual column of basalt with a pedestal of red band on a storm wave platform

FIG 6—Amphitheatre like depression in cliff top Summerland's Island

PLATE II

FIG 1 Basalt cliffs fronted by storm wave platform in the vicinity of Pyramid Rock near high tide Cape Woolamai on the skyline

FIG 2 Pyramid Rock consisting of a residual of columnar basalt surrounded by basaltic screes on a base of lighter coloured granite

FIG 3—Phelan's Bluff from Kitty Miller's Bay at high tide The Bluff consists of thick tuff beds overlying a basalt flow which rises to 14 feet above high tide level Storm waves have cut back the overlying tuff giving rise to a high level storm wave platform suggestive of recent emergence

FIG 4—Granite coast on the relatively protected south eastern side of Cape Woolamai

FIG 5—Granite coast on the exposed south western side of Cape Woolamai showing influence of joint planes on the development of rock stacks

FIG 6—Granite coast on the exposed south western side of Cape Woolamai showing the influence of the joint planes on the development of gorge like embayments

FIG 7—Sand dunes growing on the protected coast of the Eastern Passage

PLATE III

FIG 1 Small storm wave platform cut in red tuff at McHaffie's Reef

FIG 2 Cliff section through domed tuff beds at McHaffie's Reef

FIG 3—Dune ridge on the back shore at Cat Bay Tree covered dunes fronting Summerland's Island tie bar in the middle distance and Quoin Hill on the skyline

FIG 4—End of the spit fronting Mangrove Swamp west of Rhyll French Island on the skyline

FIG 5—Quarry in Jurassic rocks in the old cliffs north west of Rhyll

FIG 6 Prograded beach on Swan Corner

FIG 7—Silted up bay behind the spit extending east from Cowes looking from the top of the old cliff-line The old cliffs can be seen in the distance

FIG 8—Nip cut in prograded land at Rhyll township

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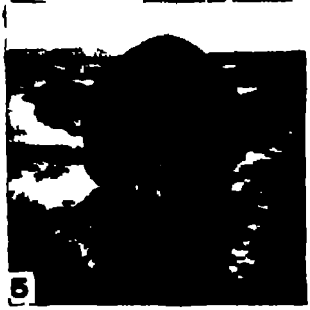
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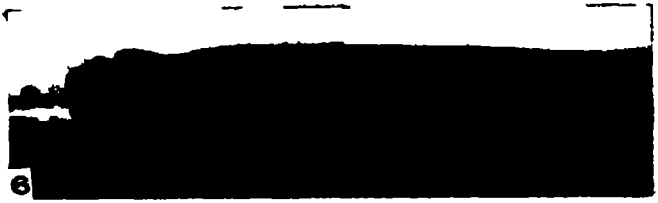
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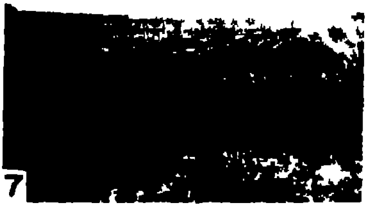

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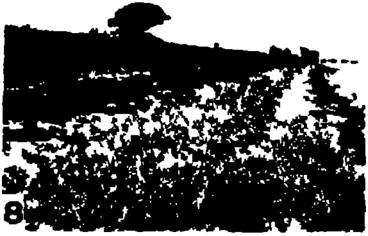

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[Proc. Roy. Soc. Victoria, 57 (N.S.), Pts. I.-II., 1945.]

Art. II.—*The Stratigraphical Range and Habitat of the* Diprotodontidae *in Southern Australia.*

By R. A. KEBLE.

[Palaeontologist to the National Museum, Melbourne.]

[Read 13th July, 1944; issued separately 10th December, 1945.]

Abstract.

Records of *Diprotodon* and *Nototherium* in Victoria, in the adjoining part of South Australia, and in King Island have been examined and in most cases more or less indefinite localities have been fixed with some precision. The beds containing the *Diprotodontidae* have also, in many cases, been identified.

Owen's locality "near Mount Macedon" for some of his paratypes of *D. australis* is recognized as a spring deposit at Lancefield.

Each occurrence is discussed from the standpoint of its stratigraphy and correlated with the terraces of the Maribyrnong valley, or, where possible, with the scoria cone flows of western Victoria.

The Diprotodontidae are believed to be restricted to the Upper Pleistocene or the upper part of the Middle Pleistocene; their appearance is subsequent to the first vulcanism responsible for the Newer Basalt. No remains have been found in beds below the Newer Basalt lava plain phase.

Their habitat is discussed and it is submitted that they flourished when the climate was wetter and the flora more luxuriant, probably during periods when the Upper Pleistocene glaciations occurred in southern latitudes.

Diprotodon is recorded for the first time from King Island, and, as it is a continental genus, it is inferred that the land bridge connecting King Island with the mainland was broken after it first appeared in Victoria, i.e., in the Upper Pleistocene or the late Middle Pleistocene.

The validity of *D. longiceps* as a species is confirmed by a re-examination of McCoy's holotype.

Introduction.

There are records of *Diprotodon* and *Nototherium* from a number of places in southern Australia; this contribution deals with those in Victoria, in the adjoining part of South Australia, and in King Island. Most of the specimens were obtained before 1900 and there is a general lack of detail as to the exact positions and their containing strata. An exception is the North Melbourne specimen recorded by G. B. Pritchard (13); he published a plan on which he accurately marked the position, and in his contribution gave particulars of the stratum. On the other hand, an exhaustive search for additional particulars regarding the important Colac specimen—McCoy's (10) holotype of *Diprotodon longiceps*—has been futile and further information seems to be now unobtainable. By examining records, some of them made 100 years ago, more or less relevant additional information was obtained regarding many of the specimens. *Diprotodontidae* from the following localities have been dealt with:—

1. North Melbourne.
2. Footscray.
3. Duck Ponds.
4. Limeburner's Point.
5. Lancefield (Mount Macedon).
6. Talbot (Back Creek).
7. Lake Colongulac (Lake Timboon).
8. Colac.
9. Omeo.
10. Buninyong.
11. Coimadai.
12. Watch Hill (? "Murchill").
13. Melton.

The occurrence of *Diprotodon* at Portland and the Goulburn River is mentioned in correspondence but no other particulars are given. Information regarding the molar of *D. australis* (No. 14403) obtained on King Island, and which is here recorded for the first time and discussed from the standpoint of the range of *Diprotodon*, has been supplied by the finder Mr. J. Graham Haines of King Island.

The stratigraphical range of *Diprotodon* and *Nototherium* is correlated here where possible with the succession of fluviatile terraces in the valley of the Maribyrnong River worked out by R. A. Keble and J. Hope Macpherson, more detailed particulars of which are to be published shortly in the Memoirs of the National Museum, Melbourne. Some occurrences are correlated with the succession of lava flows and tuffs implied by H. J. Grayson and D. J. Mahony's Memoir (5) on the Camperdown and Mount Elephant districts. *Nototherium* has been found in the same bed as *Diprotodon* at Talbot (Back Creek), Lancefield (Mount Macedon), and Omeo. At Buninyong, Coimadai, Watch Hill (?), and the bed of a creek about 1 mile north-east of Melton it occurs without *Diprotodon*.

The *Diprotodon* and *Nototherium* remains at North Melbourne, Footscray, Duck Ponds, Limeburner's Point, and Coimadai were found in fluviatile or lacustrine beds deposited in tributary valleys of the Yarra stream system. The bathymetrical contours of Port Phillip Bay—a sunkland on which the lower reaches of the Yarra stream system have been submerged—disclose delta deposits and wave platforms that may be correlated with the Maribyrnong Valley fluviatile cycles. There are no Pleistocene glacial deposits in Victoria, but Keble and Macpherson have assumed that the terraces, platforms, etc., were formed by eustatic adjustments of sea level caused by glaciations in other regions. They found that the Maribyrnong Valley was little affected by tectonic movements, which usually took the form of warping and tilting. Their succession, with a correlation with the European glacial and interglacial stages indicated by F. E. Zeuner (21), is as follows:—

Age.	European Stages.	Maribyrnong River Cycles.	Maribyrnong River Phases
Recent	Post Glacial	Present Cycle	Recent Maribyrnong Terrace
Upper Pleistocene	W3 W2/W3	Maribyrnong Cycle	Maribyrnong Flood Plain Braybrook Terrace
	W2 W1/W2	Braybrook Cycle	Braybrook Flood Plain Keilor Terrace
	W1 Pre-Wurm	Keilor Cycle	Keilor Flood Plain Vertical erosion
Middle-Lower Pleistocene	NEWER BASALT (lava plain phase)		

The duration of the vertical erosion that preceded the deposition of the Keilor Flood Plain is uncertain; a Middle-Lower Pleistocene age is assumed for the lava plain phase Newer Basalt on which the vertical erosion was initiated. There is, however, an unbroken sequence back from the Recent to the Keilor Flood Plain.

Grayson and Mahony (5) divide the basalts of Camperdown and Mount Elephant into two groups, which, they say, differ in relative age and to a certain extent in character. They use the terms "earlier" and "later" for these basalts.

The origin of the "earlier" basalts (the Newer Basalt in Keble and Macpherson's succession) which are exposed over very considerable areas and up to 100 feet thick is, they state, very obscure. They state also that the lava plains—the surface of these earlier basalts—are traversed by natural drainage channels and there are on them depressions with gently sloping sides, in which water lies for long periods. But it should be pointed out that there is evidence of an earlier drainage system—old flood plains that do not now function—in the districts. No remains of the *Diprotodontidae* have been found under the "earlier" basalts.

The Hampden Tuffs, the name given to the tuffs of the districts, which cover a considerable area around Camperdown and Lake Keilambete and on the floor of Lake Bookar at Terang, are bedded and distinct from the heaps of scoria around the scoria cones from which the "later" basalts came; they were stratified while the volcano from which they came was in active operation. They may be regarded as a series intermediate between the "earlier" and "later" basalts: the "later" flows at places rest on them. Besides covering the beds of lakes within the area over which they fell, they probably also covered the drainage channels and depressions on the earlier flows and those of the older drainage system that preceded it Under the Hampden Tuffs, where drainage channels and depressions existed alluvial and lacustrine deposits probably occur and it is possible that some of the remains of *Diprotodontidae* in bone beds on the shores of lakes may have been derived from some of these resorted older deposits as for instance those of Lake Colongulac

The ' later basalts are always closely associated with the scoria cones—the points from which they were erupted The flows are often slightly raised above the general surface of the earlier lava plain and form low platforms from which the scoria cones rise In many cases the flows are of limited extent and at Mount Terang there is a good section in which four distinct flows together forming a thickness of 15 feet and associated with unstratified scoria are exposed and rest on the undenuded surface of the bedded tuffs—the Hampden Tuffs Grayson and Mahony regard the later basalts as of very recent origin and that though they are approximately of the same age some of these flows are no doubt considerably older than others and no sharp line can be drawn between them and the earlier basalts

The *Diprotodontidae* that were obtained at Talbot probably came from a lacustrine deposit formed in a lake due to the damming of Back Creek by a scoria cone flow across its outlet the sub basalt lake at Buninyong was likewise formed by damming in this case by the Yarrowee flow The Mount Gambier and Mount Schanck remains were found under volcanic ash that came from those recent craters

Grayson and Mahony's recognition of earlier and later basalts and the intermediate Hampden Tuffs in the Camperdown and Mount Elephant districts is taken here to apply generally to the volcanic activity throughout Victoria known as the Newer Basalt In interpreting the geological maps it has been found convenient to refer to the earlier basalts as the lava plain phase and the later basalts as scoria cone phase

Up to the present it has not been found possible to correlate the cycles of erosion and fluviatile deposits of the Maribyrnong Valley with the Hampden Tuffs and the scoria cone flows the only correlative datum is that both series post date the lava plain phase But every horizon in the bedded Hampden Tuffs each scoria cone flow and each fluviatile and lacustrine deposit in the Western District is contemporaneous with some part of the Maribyrnong Valley fluviatile deposits or river cycles It is noteworthy however that although there are scoria cones in the Maribyrnong Valley at no place is a scoria cone flow found resting on a river terrace or is volcanic ejectamenta bedded with the fluviatile deposits On the other hand there is evidence in the Dutch Ponds Valley of a lava flow, presumably from a nearby scoria cone, having flowed on to the Keilor Flood Plain, damming the stream to form the lake in which the freshwater limestones, the beds containing *D. longiceps* accumulated. The Burnley basalt also covered fluviatile deposits in the valley of the Yarra that extend into and cover the *Diprotodon* beds of North Melbourne and Footscray.

Occurrences of the Diprotodontidae.

1.—NORTH MELBOURNE.

In 1899 a fairly large fragment of the right half of the lower jaw of *D. australis* Owen was found in the excavations for the main sewer at Arden-street, North Melbourne. G. B Pritchard (13) states: "the present example was found in a tunnel excavation under the Moonee Ponds Creek near Arden-street, North Melbourne, the depth of the tunnel below the present bed of the creek being approximately 25 or 35 feet below the surface . . . The matrix in which the bone was found is a sandy clay of a fawn or brownish colour, containing glassy quartz grains up to one-sixteenth of an inch in diameter—some well rounded, while others are sub-angular—and small flakes of white mica, apparently muscovite . . . In the extension of this same sewer towards Kensington at a distance of about 200 feet from where the bone was found, numbers of marine shells were found, all of which appear to be recent species, and this close association of these remains seems to warrant the application of Pleistocene for the geological age of the deposits in the area."

The log of the bore put down where the *Diprotodon* was found by the Melbourne and Metropolitan Board of Works was—

a Filling	10 feet.
b. Silt	19 feet
c. Yellow and red clay	8 feet
d Sandy clay	17 feet.
Total depth . .	54 feet

The specimen came from bed "d."

The sequence of the fluviatile deposits and cycles of the Moonee Ponds Creek, and incidentally, the Maribyrnong and Yarra Rivers was as follows:—

Raised Beach ?.
Flood plain deposited in diverted stream (Yarra River)
Dune encroachment. Diversion of Moonee Ponds Creek and captured Yarra into the Maribyrnong River.
Capture of the Yarra by Moonee Ponds Creek after the Burnley Basalt (scoria cone phase).
Flood plain deposits—beds "b" and "c" in above log.
Vertical erosion.
Sandy clay, etc—*Diprotodon* bed, "d" in above log.

As regards the age of the *Diprotodon* bed it is either at the base of the Recent or the summit of the Pleistocene.

2.—FOOTSCRAY.

In January, 1899, *D. australis* was found in Footscray. The specimen (No. 13,000) represents most of the left ramus of the lower jaw with its fore part and symphysial boss: in their sockets are three worn molars (MI, 2 & 3), two imperfect pre-molars (D3 & 4), and the socketed portions of two broken-off incisors. It was found at a depth of 36 feet in sewerage excavations. These are all the facts that have been recorded concerning the specimen, but old records kept by the Melbourne and Metropolitan Board of Works enable its locality to be fixed within narrow limits.

The depth from which it was obtained indicates that it came from excavations for a main sewer. In 1899 and previous to that year, in Footscray proper, only the excavations for the main sewer between the Maribyrnong River and Lloyd-street reached a depth of 36 feet. The area on the left bank for some distance to the east was then part of Footscray and the excavations in this part were also 36 feet deep but gradually shallowing to the east. The bores put down by the Board on the right bank were in the lava plain phase of Newer Basalt except Bore No. 43 which was on the toe of the bank 200 feet downstream from the Napier-street Bridge. The log of this bore was—

a. Filling	4 feet.
b. Silt	5 feet.
c. Clay	35 feet.
d. Sand	2 feet.
Total depth	46 feet.

A section across the Maribyrnong River available from the logs of bores put down by the Railway Department along the Footscray to Melbourne railway line about ¼ mile to the north of the sewer shows a few feet of sand resting on river silt and mud, which occupies a river channel cut in sandy clay. The matrix adherent to and in the crevices of the jaw bone is a clay containing coarse quartz sand and there is little doubt that the *Diprotodon* came from bed "c" in the log of Bore No. 43.

The Footscray sewer is the westerly extension of that at North Melbourne in excavating which Pritchard's *Diprotodon* was found, and the containing bed at Footscray is probably a westerly extension of the North Melbourne bed.

3 AND 4.—DUCK PONDS AND LIMEBURNER'S POINT.

R. Daintree (4) states in his report on Quarter Sheets 19 S.E., 24 N.E., and 24 S.E.: "The deposits of freshwater limestone at Limeburner's Point, Geelong, and the Duck Ponds, appear to have taken place just after the close of the volcanic period, and before the subsidence of the land to receive the sea which deposited the Queenscliff beds."

Diprotodon has been found at both places, and judging by the similarities in the fossil freshwater shelly fauna and the lithology of each deposit they were deposited under the same conditions and were contemporaneous. The geological history of Duck Ponds, sometimes referred to as Duck Ponds Creek or Hovell's Creek, is clearer than that of Limeburner's Point and is dealt with here at some length.

3.—DUCK PONDS.

The exact locality and the bed from which the upper and lower incisors (No. 1892-3) identified by McCoy (10) as belonging to *Diprotodon longiceps* were obtained by the Rev. C. S. Y. Price, has not been recorded. The specimens are so well-preserved—there is little mineral replacement and an absence of adherent matrix—that a doubt arises as to whether they were *in situ*. A note on Quarter Sheet 24 N.E., viz., "Lime kilns in excavating which several bone caves were found," increases this doubt. In the absence of information to the contrary, however, and the fact that the Limeburner's Point specimen was definitely *in situ* in what appears to be the same bed, it has been assumed that the Duck Ponds specimens were obtained from the limestone.

Daintree in Quarter Sheets 19 S.E. and 24 N.E. shows the Duck Ponds freshwater limestone as occupying the valley of Duck Ponds Creek. The succession shown by him on those Quarter Sheets may be tabulated as follows:—

A	Alluvial, fluviatile and swamp deposits	Recent
Pl	*a.* Estuary beds; *b.* Raised beaches	Post Pliocene
TP^N	Calcareous clay, sandy beds, gravel	Newer Pliocene
L	Freshwater limestone	Tertiary
V	Upper Volcanic [lava, plain phase]	Pliocene
TP	Sandy beds, clay, shale	Older Pliocene
TM	Marine limestones, clays, &c.	Miocene

The following is an interpretation of the succession in terms of sedimentation and stream development derived from surface physiographical evidence: the lava plain phase of the Newer Basalt obliterated all earlier physiographical features. The symbols used on the Quarter Sheets in the foregoing summary of Daintree's succession are given to facilitate comparison with it and the cycles and terraces worked out by Keble and

Macpherson in the Maribyrnong River Valley It will be noted that the Upper Volcanic (V) or Newer Basalt lava plain phase is regarded as Lower Middle Pleistocene, not Pliocene, the age assigned to it by Daintree

1	A	Alluvial fluviatile and swamp deposits	Recent
2	Pl	Estuary beds raised beaches	
3		Rejuvenation	
4		Low level flood plain deposits in tributaries	Maribyrnong Cycle
5		Rejuvenation Breach of dam	
6		High level flood plain deposists in tributaries following 7	? Braybrook Cycle
7		Vertical erosion	
8		Regional subsidence on Lovely Banks Monocline	Keilor Cycle
9	TPN	Calcareous clay sandy beds gravel &c	
10	I	Deposition of *Diprotodon* fresh water limestone	
11		? scoria cone flow dams Duck Ponds valley	
12		Flood plain deposits in railway bores following 13	
13		Vertical erosion of Duck Ponds Creek	
14	V	Upper Volcanic (lava plain phase)	

Sections of the freshwater limestone (L) disclosed by wells and bores put down by the Railway Department show that it rests on flood plain deposits A well sunk at its northern extremity gave the following section particularized on Quarter Sheet 19 S E —

TPN	Soft sandy loam	4 feet
I	Rubbly limestone	6 feet
	Compact limestone containing fresh water shells Planorbis Limnaea	4 feet
	Soft rubbly limestone	6 feet
	Calcareous sandy clay	4 feet
V	Soft decomposed basalt	2 feet
	Total depth	26 feet

The bores put down for the Railway Department were for the foundations of the bridge to carry the Geelong-Melbourne railway over Duck Ponds Creek The deepest bores reached a depth of 30 feet below sea level and passed through intercalated muds, clays, sands and gravels only one bore encountered limestone—a bed 5 feet thick—5 feet above sea level The significant information supplied by the bores is that 21 feet under the bed of Duck Ponds Creek a bed of quartz gravel and rotten shells" overlies stiff clay, unfortunately we are not told whether the "rotten shells were freshwater or marine The horizon of the single bed of limestone is 14 feet above the shelly quartz gravel The bores penetrated other shelly beds lateral extensions of the tidal deposits at present tide limit in the bed of the Creek On Quarter Sheet 24 N E there is a reference to a cliff section showing about 20 feet yellow sandy limestone this limestone is at a higher horizon than any of the beds disclosed by the railway bores The combined deposit shown on the Quarter Sheets as freshwater limestone (L) is about 70 feet thick 40 feet of which are mostly freshwater limestone and 30 feet almost exclusively flood plain non-calcareous deposits The bores passed through for the most part flood plain deposits of the stream formed during the first cycle of erosion after the Newer Volcanic i e the Keilor cycle This flood plain is correlated with the Keilor flood plain of the Maribyrnong Valley—the first flood plain formed in that valley The freshwater limestones of Duck Ponds Creek are newer—the upward lacustrine extension of the flood plain deposits—but there was little if any time break between the two deposits

The flood plain deposits of the Braybrook cycle are probably represented in the gully artificially dammed to form a lake north of Lara and also in the gully similarly dammed to form Lara Lake The flood plain deposits in the lower reaches of this Lara Lake gully have been correlated with the Maribyrnong cycle

Summarizing these remarks the age of the Duck Ponds incisors of *Diprotodon longiceps* are early Upper Pleistocene and the containing beds a late equivalent of the Keilor Flood Plain in the Maribyrnong River Valley succession

4—Limeburners Point

Limeburners Point or Galena Point as it is called on Quarter Sheet 24 S E and most maps is on the south side of the Inner Harbour of Corio Bay it rises rather steeply from the sea to a height of about 70 feet Quarter Sheet 24 S E was surveyed in 1863 by R Daintree (4) and the following are the particulars of the limestone given by him in his report on the Sheet The section afforded in the thickest part of the limestone deposit at Limeburners Point is—

7 feet	Marly clay	Marine Shells
10 feet	Ferruginous sandy clay with marine shells	
3 feet 6 inches	Rubbly limestone	Freshwater shells Planorbis Lymnea &c
3 feet 6 inches	Thin bedded limestone	
7 feet	Very compact limestone principal bed used for lime	
6 feet	Rubbly thin bedded ferruginous limestone resting on Miocene tertiary sandy marl	

This closely agrees with Note 3 printed on the margin of the Sheet

It will be noted that the freshwater shells are identical with those obtained in the well (p. 30) in the Duck Ponds limestone. *Diprotodon longiceps* was obtained *in situ* in the 7-ft. bed of "very compact limestone." The specimen (No. 13303) identified by McCoy (10) shows a horizontal section of the molars and a vertical section of the incisors.

The freshwater limestone (L) outcrops at and extends some feet above and below sea level, a fact that clearly indicates a relative subsidence of the freshwater beds. The calcareous clay, sandy beds, gravel, etc. (TP^N), overlie both the lava plain phase of the Upper Volcanic (V) and the freshwater limestone (L); and in some places the Miocene sediments. The interpretation of the geology of Limeburner's Point is somewhat difficult owing to the area to the north being one of subsidence and submerged by the water of Inner Harbour. There is little doubt, as Daintree asserts, that the limestones of Limeburner's Point and Duck Ponds are of lacustrine origin and contemporaneous; their lithology and fossils are identical. At Limeburner's Point the lacustrine limestone rests on the scarp of the sink that formed the Inner Harbor; it outcrops from 25 to 70 feet below the surface of the upper Volcanic (V) presumably the extension southwards of that in the Duck Ponds Valley on which there the limestone and fluviatile beds rest. The 17 feet of marly and ferruginous sandy clays containing marine shells are probably partly a raised beach.

The succession of events has been—

	Duck Ponds Equivalent
1. Raised Beach	2
2. Regional subsidence and marine transgression forming Inner Harbour	8
3. Widespread deposition of calcareous clays, sandy beds, gravels, &c., (TP^N) on the surface of the freshwater limestone (L), Upper Volcanic (V), and Miocene sediments	9
4. Deposition of the *Diprotodon* freshwater limestone (L) in the sink and on its scarp	10
5 Tectonic sink during the Keilor Cycle	

5.—Lancefield (Mount Macedon).

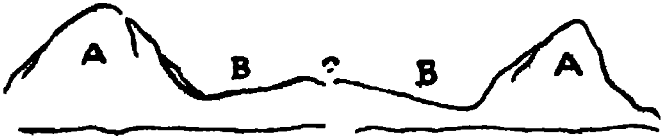
In 1844 Richard Owen (12) in a report to the British Association for the Advancement of Science on the extinct mammals of Australia spoke of some fossils received by the Royal College of

Surgeons, London, from Dr. Hobson of Melbourne. The following is an acknowledgment to Hobson by Owen of the receipt of the fossils :—

> Rl. College of Surgeons,
> August 26th, 1844.
>
> My dear Dr. Hobson,
>
> I lose no time in gratefully acknowledging the reception of the interesting series of fossils discovered by Mr. Mayne, which you have been so good as to transmit to me, as also the well-marked cranium of the Native of Western Australia. You will perceive by the accompanying sheets that no time has been lost in describing the fossils. They came just as I had completed the catalogue of that series in our Museum and I stopped the press to include your interesting Australian fossils.
>
> Every specimen, except 1498 and 1502, belong demonstratively to the large Marsupial Pachyderm first indicated in Major Mitchell's "Expeditions," Vol. II., p. 362, pl. 31, f. 1 and 2 under the name of *Diprotodon*, signifying two incisors; a genus which I regarded as having an affinity to the Wombat, and which affinity appears to be demonstrated by the calcaneum from the Condamine River transmitted to me by Sir T. Mitchell about a year ago, together with portions of jaw and teeth of *Diprotodon*.
>
> The molar dentition agrees, like that of *Macropus*, in form with that of *Tapirus* and *Dinotherium*, so that altogether the *Diprotodon* is one of the most interesting forms that has been rescued from the great devourer of all things.
>
> I trust that you may be able, through Mr. Mayne and other energetic collectors, to obtain the materials for a complete restoration.
>
> You will perceive also in the descriptions of Nos. 1505-1509, the evidence of an allied genus.
>
> I never had a fossil bone which excited my interest more than 1509, the astragalus of most assuredly a marsupial as large as a Rhinoceros, yet quite distinct from Kangaroo and most like Wombat
>
> Depend upon it your alluvial or newer tertiary deposits are the grave of many creatures "which have not been dreamt of in our philosophy."
>
> I shall give a sketch of the facts to the Meeting of the Br. Assn. at York, illustrated by Colonel Mitchell's and Mr. Mayne's fossils together with some (including a true Mastordon) brought home by Count Strzlecki or Strelingski, who has returned rich in well observed facts from Australia.
>
> always your most sincerely,
> Richard Owen.

Owen used the specimens as paratypes of *Diprotodon australis* to explain the dentition of young forms. In 1877 (12) he states: "In 1845 I described and figured a series of teeth, discovered in sinking a well near Mount Macedon, Port Phillip, Province of Victoria . . ." and quotes a letter (13) from Hobson dated January 1, 1845, the portion relating to this discussion being—

"Amongst the secondary hills which skirt the base of Mount Macedon there is a considerable circular plain, which is most elevated in the centre than at the circumference, and which will be better explained by a diagram.



A. A. Volcanic Hills surrounding the plain.

B, B. The plain.

C. A swamp or bog in which are found the bones at a depth of 4½ feet. After digging through a solid peaty soil for 3 feet you then arrive at a stratum of gravel about 18 inches thick, in which the bones are deposited. This layer of gravel rests upon a bed of firm clay, which is unfossiliferous.

The bog or marsh in which the bones are found is about 4 acres in extent, and appears to contain bones at every point. I opened two pits at 150 yards distance from each other and found bones in both, in the same stratum of gravel."

Owen (12) also mentions that in 1844 he received bones from Patrick Mayne from "freshwater beds, Mount Macedon": Mayne informed him by letter that they were "found about 6 feet below the surface in sinking a well." Owen in his report to the British Association alludes to the fact that bones from the same locality as Hobson's came from, were described by F. A. Greeves in a letter to The Port Phillip Patriot on February 3, 1844. In this letter Greeves states that Mr. Mayne made the discovery "in alluvium" near "Mt. Macedon" and that he (Greeves) believed the bones to be the remains of a gigantic wombat. They were brought to Melbourne by Mayne and were subsequently presented to the Museum of the Melbourne Mechanics' Institute; one limb bone (No. 13005) eventually found its way into the collection of the National Museum.

Hobson (8) published an extract from a letter dated February 21, 1844, headed "On Some Fossil Bones discovered at Mt. Macedon, Port Phillip" in which he states—

> "the fossil bones of a number of extinct animals have been discovered by Mr. Mayne, near Mount Macedon . . . in a small marsh about 5 feet beneath the surface, embedded in a layer of dark alluvium, about a foot in thickness, upon which are superimposed a bed of yellow clay, and a rich black soil next the surface. The country in the neighbourhood is volcanic and covered with scoriae and vesicular lava."

Hobson (7) also published a letter dated January, 1845, from himself to Ronald C. Gunn, of Launceston, in which he states—

> "The bone locality is a large amphitheatre almost surounded by conical volcanic hills; the centre of the amphitheatre is on a much higher plain than its periphery, and on the top of the little truncated cone there is a marshy looking place covered by a peaty looking vegetation and the soil itself has much the character of peat for three or four feet below the surface. Under the peat is a bed of gravel, in which the bones are deposited in vast quantities, but from there being immediately beneath the bed of gravel a bed of firm ferruginous clay, the water is unable to escape, and in consequence, at this period of the year, it is a work of great labour to obtain any bones and quite impossible to get them without mutilation, owing to the water pouring in to the part dug so fast as to prevent your seeing what you are about. Notwithstanding all this, and we were there only one day,

I succeeded in getting one incisor of an enormous Rodent fully *twelve inches long* and *one and a quarter inches broad* with three huge molars fully *four times as large as those of a Rhinoceros;* with bones of the gigantic kangaroo and those of some large cursorial bird, probably an Emu. The marsh or bog is of the extent of about four acres, and appears to contain bones at every point."

Hobson (8) published an extract of another letter from him to Gunn dated June, 1845, stating that Owen had identified all the specimens from Port Phillip as *Diprotodon* except two; in addition he had identified *Nothotherium*.

It is to be noted that Hobson clearly states that he obtained his bones from a bed of gravel and that both Hobson and Greeves state that Mayne obtained his bones from a (dark) alluvium; both were stated to come from "near Mount Macedon." In the table of localities of *D. australis* published by Owen (12) in 1877 he states that Hobson's bones came from Quaternary gravels and Mayne's from freshwater beds.

The locality given for the discovery "near Mount Macedon" has been a matter for conjecture since Owen (12) published it; an examination of old records makes it clear that the locality was actually Lancefield.

In the early forties—up to 1848—James P. Mayne held the Lancefield Run; it passed from him to Dunsford, who took up the pre-emptive right immediately east of the town of Lancefield. The site of the town was part of the Run and sometimes referred to as Five Mile Creek The town was surveyed in 1854 and does not appear on the maps of Victoria published before 1850 by Skene and Ham In 1855 William Blandowski (2) refers to this central part of Victoria as "the ranges known as Mt. Macedon itself." He observes: "Some distance N.E from the peak of Alexander's Head is a spot where the discovery of bones of gigantic antediluvian *fossil birds* took place, five or six years ago, in a basaltic cavern I was much disappointed at my ineffectual endeavours to obtain similar specimens, in consequence of my inability to suppress the springs of water sufficiently to enable me to reach the proper depth" The references to "fossil birds" and "a basaltic cavern" are two of the many mistatements found in Blandowski's descriptions, but there is little doubt that he visited the locality where Mayne and Hobson found their bones. In 1863 Norman Taylor (18) stated: "About 1 mile S.W. of Dunsford's (Map 5 S.E.) are 'The Spring' where in digging a waterhole some years back, Mr. Mayne found some gigantic fossil bones at a depth of from 3 to 4 feet There is no cavern there as stated by Mr. Blandowski." Taylor's reference to the mythical cavern dispels all doubt about them both having visited the same place; the directions given by each, although from different starting points, would bring them to Mayne's bone bed.

On June 14, 1858, about the time Quarter Sheet 5 S.E. was being surveyed by Taylor, McCoy wrote to Owen:

> "we are now trying to find some more of the large mammalian remains by excavating in the swamp near Mount Macedon in which were found the large jaws and teeth and bones of extremities sent home to you by Dr Hobson . . . ."

An inspection of the locality indicated by Taylor enables one to fix the swamp where Mayne and Hobson obtained the bones more than a hundred years ago; it is referred to as the "Bone Bed" near the spring on the accompanying sketch map (fig. 1). The

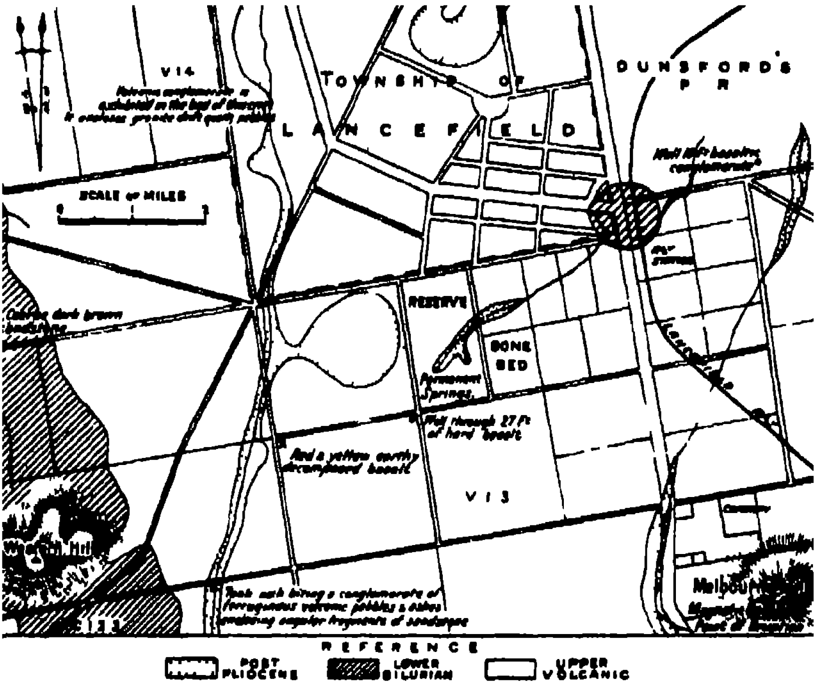


Fig. 1

eye of the spring has been interfered with and the peaty bed has been turned over by digging at the surface, there is no evidence of gravel having been brought up, but there are pieces of Palaeozoic bedrock lying about suggesting that former excavations may have reached bedrock If so, the gravels could be resting on bedrock and be stratigraphically older than the basalt In the following sections mentioned in Hobson s correspondence the date of the letter is given —

21 1 1844	ft in	1 1 1845	ft in	1 1845	ft in
Surface		Surface		Surface	3 0 or
Black soil	4 0	Peaty soil	3 0	Peaty soil	4 0
Yellow clay		Gravel (bone bed)	1 6	Gravel (bone bed)	
Dark alluvium (bone bed)	1 0	Firm clay unfossiliferous		Firm ferruginous clay	

Bedrock does not appear to have been reached in any of the sections

The spring apparently owes its existence to sub basalt or inter basalt waters finding their way to the surface but whether through a fracture in the basalt or some part of the basalt has been removed by erosion is not clear The overflow of the spring has cut a shallow valley trending north east obviously the direction of the slope of the lava plain Near the spring it is cut in peaty beds but further to the north east is as shown by Taylor on the lava plain it and the peaty soil are newer than the basalt

As *Diprotodon* and *Nototherium* were attracted to the locality by the spring which must obviously be later than the lava plain phase of the Newer Basalt their remains must likewise be later It is conceivable however that the basalt cover from beneath which the spring water comes is a scoria cone flow This could not be determined without much detailed work but it may be mentioned that the scoria cone of Melbourne Hill about 1 mile to the south east—the nearest scoria cone to the spring—stands on what is assumed to be the lava plain phase of the Newer Basalt

6—TALBOT (BACK CREEK)

McCoy (10) with his usual lack of precision in defining localities records *Diprotodon* and *Nototherium* from Back Creek There are so many Back Creeks in Victoria that its identification would have been impossible but for an amended address in one of his letters a copy of which is kept at the National Museum to the finder of the fossils On October 23 1861 he wrote to Rob Wilkinson chemist Back Creek

> Prof McCoy as Director of the National Museum of Victoria presents his compliments to Mr Rob Wilkinson and begs to say that having examined with great interest the specimen sent to the International Exhibition by him from Back Creek two of them viz one extremity of a long bone and one curved fragment of a tusk would be of the highest interest as additions to the National collection in the Public Museum

Wilkinson's reply is not filed but McCoy's next letter to him on October 29, 1861, is informative. It is addressed to Rob. Wood Wilkinson, chemist, Talbot (late Back Creek):

and thanks him for "his letter of the 28th inst, and in reply begs to say that even as a temporary deposit the specimens will be received with great interest . . ."

Thus, although McCoy did not succeed in cadging the specimens for the National collection, in attempting to do so, he unwittingly identified the Back Creek from which they came; the creek of that name flowing through Talbot. Mr. Baragwanath, Director of the Geological Survey of Victoria, informs me that Talbot in the early mining days was always known as Back Creek. The entry in the catalogue of the 1861 Exhibition records the exhibit as: "212 Wilkinson, R. W., Back Creek—Geological Specimens, etc."

McCoy (10) figures a middle incisor of the upper jaw, which he says may belong to *D. longiceps.* In his explanation of the plate where he gives three aspects of it he describes it as "portion of the anterior incisor of the upper jaw of a *Diprotodon* from Back Creek" and figures the "lower tusk of *Nototherium*" also from Back Creek

Back Creek has its source about 7 miles south-west of Talbot and flows over a wide flood plain in a mature valley set in undulating Ordovician country through the town of Talbot. Near the northern boundary of the town it passes on to a lava flow of the scoria cone phase that covers the Mount Greenock Lead, continues northerly on the lava for about 1 mile and is joined there by the Daisy Hill Creek; the confluent streams then flow in a lateral valley on the west side of the lava flow. Before the lava covered the Mount Greenock Lead, Back Creek joined the Lead about 2½ miles north-east of Talbot. Most of the lava that covered the Lead came from the scoria cone of Mount Greenock The lava covered the main valley but did not encroach far on the tributary valley of Back Creek, and there is no lava in that valley upstream from Talbot to its source. Mr. Baragwanath informs me that the lava across Back Creek's outlet dammed its waters and a lake was formed some distance upstream. This lake has been drained by a stream, now the lower part of Back Creek, cutting back southwards and breaching the dam.

In the Back Creek Valley upstream from the lava there are, then, two distinctive deposits—

(*a*) Lacustrine silty black clay and impure diatomite, both newer than the Mount Greenock lava.

(*b*) Fluviatile clays and sands that are older than the Mount Greenock lava

The lacustrine beds rest on the fluviatile clays.

We do not know whether the *Diprotodon* remains came from "a" or "b." From what has been learned of the habits of *Diprotodon* in Victoria there is a strong presumption that they came from the lacustrine deposits. If, however, they came from the fluviatile deposits, the depth is important, for while the surface fluviatile beds are approximately the same age as the Mount Greenock scoria cone flow, the underlying beds as the depth increases become successively older.

7.—LAKE COLONGULAC.

Lakes Colongulac (Timboon), Corangamite, and Colac belong to what Grayson and Mahony (5) term the Colongulac type of lake: "these shallow basins appear," they state, "to occupy the natural depressions which occur between lava flows, and which have been deepened during times of drought by the wind blowing away the dry mud from their beds and increased in size by the action of the waves on their banks." Probably all the lakes of this type, which have no well-marked streams entering them and no outflow, started as shallow depressions filled with alluvium. The depressions were in the lava plain phase of the Newer Basalt and the Hampden Tuffs must have fallen in them if they were within range; tuffs falling in a depression presumably rest on alluvium or have been re-deposited as alluvium.

Bones of many marsupial genera have been found on the shores of Lake Colongulac, and Grayson and Mahony show on their Quarter Sheets (8 N.E. and 17 S.E. (New Series)) of the area "Bone Beds, *Diprotodon* Beds" on the shores of the Lake. The bone beds appear to be newer than the Hampden Tuffs, but most of the bones were found loose on the shores of the Lake and it is not certain whether they came from the bone beds, the Hampden Tuffs, or the re-deposited alluvium. There are no particulars of the beds from which a limb bone—a humerus presented by Dr. Greeves—and a leg bone in the Sweet Collection, both belonging to *Diprotodon*, came.

The succession in the district may be summarized—

Alluvium.
Dunes of redeposited Tuffs.
Scoria cone basalts.
Bone Beds. *Diprotodon* Beds
Hampden Tuffs.
Buckshot Gravels.
[Alluvium in old valleys and depressions].
Newer Basalt (lava plain phase).

8.—COLAC.

The lower jaw with molars and incisors (Holotype No. 12109) of *Diprotodon longiceps* described by McCoy (10), the description of which is checked here, was obtained "in sinking a well in the Pliocene clays of Colac." An exhaustive search has revealed no additional facts about this important specimen. It may be assumed that the well was not deeper than 30 feet, and it is stated that the specimen was obtained in sinking it. The jaw is fragile and shows considerable decalcification the small amount of the containing bed adherent to it is light coloured and suggestive more of a Holocene sedimentary clay than a basaltic clay It may have come from the Holocene surface beds immediately south of Colac at any rate McCoy had not sufficient evidence when he described the specimen to say that the containing bed was Pliocene

In the Sweet Collection at the National Museum there is a femur of a *Diprotodon* from Colac a portion of the containing bed adherent to the specimen is a stiff basaltic clay quite unlike that on the holotype In the Melbourne University collection there is a lower incisor of *D australis* also from Colac

Some doubt has been cast on the validity of *Diprotodon longiceps* McCoy as a species Stirling and Zietz (17) maintain "that while some of the Callabonna fossils certainly reveal the dental features of what [McCoy] has based his determination of [*D longiceps*] we believe that we shall be able hereafter to show the characters in question do not amount to more than variations which are to be observed within the limits of Owen's original species But McCoy bases his species on other characteristics besides the dentition The measurements given by him (10) in his description and figures of the Holotype (No 12109) differ and they have for that reason been checked Since he examined the holotype its anterior portion has been damaged the measurements in his description must be accepted for the lower incisors and diastema and it may be stated incidentally that where it is possible to check them they have been found to agree The following is his description (10) with the measurements converted to millimetres —

> Lower incisors perfectly straight with no trace of the upward curvature of *D Australis* (Ow) length 343 mm (*D Australis* only 254 mm) circumference at emergence from socket (127 mm from tip) 133 mm longitudinal extent of worn surface 76 mm greatest width 28 mm being as long as but narrower and more oblique than the same part of *D Australis* the wearing is in three planes corresponding to the three upper incisors opposed to it on each side transverse section at point of emergence from socket oblong with obtusely rounded angles vertical diameter 49 mm transverse diameter 37 mm outer side slightly concave longitudinally above the middle other sides slightly convex less than two thirds of the incisor is in socket which extends backwards to vertical with line separating first molar with last premolar surface of enamel with minute irregularly contorted vermicular longitudinal wrinkles and intervening irregular small pits and pores
>
> Diastema From anterior upper edge of the incisor socket to second molar (D 4) 152 mm and is consequently much longer than the corresponding part in *D Australis* which is only about 114 mm and it rises at a much smaller angle (angle with incisor at socket 17° compared to 20° 30°) as it recedes from the incisor

The posterior portion is undamaged and as it was when McCoy examined it Check measurements (*a*) of the molars of both rami have been made also (*b*) of McCoy's line figures (10) of molars 'natural size viewed exactly from above and in profile for the greater convenience of more exact comparison with the figures of *D. australis* (Ow), in Prof Owen's Memoirs than the oblique views in the lithographic plates would permit . . . ," and (*c*) from McCoy's printed description.

The first molar is missing.

(*a*) *Check* Anterior posterior measurements			(*b*) *Line Block*	(*c*) *Printed Description*
	right ramus	left ramus		
D4	28 mm	33 mm	30 mm	28 mm
M1	44	43	44	44
M2	49	49	49	55
M3	53	55	52	58
Transverse measurements				
D4	21	23	21	23
M1	28	28	29	28
M2	31	31	33	38
M3	35	37	36	38

There is closer agreement between (*a*) and (*b*) than between them and (*c*)

The following comparison is between *D. longiceps* (10) and *D. australis* (12) —

	D longiceps	*D australis*
Age of Specimen	mature	fully grown
Lower Incisors	perfectly straight	nearly straight, upward curvature
Length	343 mm	254 mm
Circum	133	110
Dia vert	49	42
trans	37	34
Socketed	2/3	2/3
Diastema—		
Extent	152	102
Angle with incisor	17°	20°–30°
Molars—		
Ant post		
D3	missing	missing
D4	30	26
M1	44	47
M2	49	58
M3	52	61
Transverse		
D4	21	25
M1	29	36
M2	33	41
M3	36	41

McCoy (10) states that *D. longiceps* equalled in size *D. australis*, but this is doubtful. From the tips of the lower incisors to the hind portions of the last molars, the distance is, in *D. longiceps* 444 mm. and in *D. australis* 508 mm Even with its longer incisors the distance is shorter in the first than in the second species; the distance occupied by the diastema and molars is 330 mm. in the first and 381 mm. in the second species, and thus commensurately shorter. Except D4, the molars of *D. longiceps* are all shorter in anterior posterior diameter, and there are noticeable differences in the transverse diameter. The distance between the rami opposite the third molar is in *D. longiceps* 70 mm. and in *D. australis* 95 mm

Although the growth of the lower incisors was persistent, the fact that in *D. longiceps* (mature age) they were longer than in *D. australis* (fully grown) is of specific importance. The incisors were also straighter and worn in planes due to the characteristic set of the upper incisors, the diastema was less inclined and half as long again, the teeth were on the whole smaller and the distances between the rami shorter—these facts suggest a narrower head and that the animal is entitled to specific rank.

McCoy also records *D. longiceps* from Talbot (Back Creek), the Duck Ponds, and Limeburner's Point; it must be conceded, however, that the material from these localities is unsatisfactory.

9.—OMEO.

As the exact locality of the Omeo specimens of *Diprotodon australis* Owen, *Nototherium victoriae* Owen, and *N. inerme* Owen is not given, it is not possible to fix their stratigraphical position. D. E. Thomas (19) discusses Lake Omeo and the three physiographical cycles incidental to the development of the Lake during which changes in the stream direction in the basin took place. "The Final Events have been," he states, "the deposition of the extensive alluvial flats in the lake basin and adjoining valleys; the formation of alluvial fans across the outlet of the lake; the building and subsequent breaching of the dune, and the reversal of the drainage from the north of the lake." In another place he says (19): "The effusion of lava dammed back the waters of Morass Creek and during this period the extensive flats were deposited. Morass Creek eventually cut through the barrier and formed a narrow gorge through which the lakes that were becoming silted up were drained. Lake Omeo is thus a relic of a more extensive lake system."

R. A. F. Murray (11) states that the basalt is part of the Older Basalt, that is its age is Lower Tertiary. On the Geological Map of Victoria (8 miles to an inch), however, its age is shown to be the same as the Newer Basalt in western Victoria and, since its configuration (*cf.* E. S. Hills) conforms to a lava infilled valley of the post-Older Basalt cycle of erosion, the map is probably correct. The lacustrine and fluviatile beds of the Lake Omeo basin are, then, either Pleistocene or Recent.

10.—BUNINYONG.

In 1897 marsupial bones were found in the workings of the Great Buninyong Estate Mine, about 1½ miles south of Buninyong Railway Station. One of the fragments has the appearance of having been shaped by human agency and from that aspect has been widely discussed; it was stated by C. W. De Vis (20) to be "part of the distal half of a right rib, the seventh or eighth, of an animal so large that it could only have been one of the great Nototheres in all probability *Nototherium mitchelli* Owen."

T. S. Hart (6) described the bed in which the bone was found and its stratigraphical position. The containing bed was part of a lake deposit—a stratified black clay with much carbonaceous matter resting on a bouldery bed consisting of blocks of basalt and Ordovician bedrock. The bones and the containing bed were pyritised; the bones themselves were much fractured. A small gutter below the black clay was worked in the mine until the gutter stopped abruptly against volcanic ejectamenta. Hart (6) suggests that the abrupt termination and the position of the ejectamenta are probably associated with an actual vent, and succession of vents, or the local subsidences in the neighbourhood of a volcanic vent. These would be explosive vents presumably through and subsequent to the Buninyong basalt, a flow belonging to the scoria cone phase. The gutter was that of the Devonshire Lead worked under the Buninyong basalt from several shafts. The stratigraphical position of the black clay is, therefore, above the gutter and below the Buninyong basalt.

Hart (6) says that the Buninyong basalt overlies the Yarrowee flow known at Ballarat as the "First Rock," another scoria cone flow The Buninyong flow is the newest of the flows in the Ballarat District and judged by the amount of erosion was not in his opinion of any great age. He considers, however, that a considerable time elapsed between the Yarrowee and the Buninyong flows.

It appears, then, that the lake containing the *Nototherium* bone was formed by the damming of a creek, valley, or gutter by a lava flow, probably the Yarrowee flow, and as the bones were found in that part of the lacustrine clay resting on the bouldery bed above the gutter, they are slightly younger than the Yarrowee flow Hart says that the bones are referable to "a comparatively recent period."

The Buninyong basalt is probably contemporaneous with some of the flows from the latest scoria cones in the Camperdown District and the Mount Greenock flow at Talbot.

11 —COIMADAI.

A. L. Coulson (3) mentions that with other marsupial remains found at Coimadai were "*Nototheridae*: several bones not referred to any definite genus;" it is assumed, therefore that *Nototherium* occurs in these mammalian beds—the sands intercalated with the limestone, to which he ascribes a Pleistocene age.

The limestone, he states, was chemically precipitated in a small lake just before, during, and after the eruption of Mount Bullengarook, the lava flow from which filled the valley of the old Bullengarook River but did not encroach on the lake. He says that the basin containing the lake probably owed its origin to unequal consolidation of the underlying gravels but he mentions also, that it was possibly assisted by the damming of the River in its southern part, by one of the earlier flows of Newer Basalt. The second possibility suggested by him seems to be more plausible for it is difficult to envisage the formation of such a lake unless it was dammed by a lava flow. A fault—the Djerriwarrh Fault—is stated to cross the lower reaches of the Bullengarook River near the limestone but its reputed downthrow side is to the south; it played no part in the damming. The scoria cone flow from Mount Bullengarook was preceded by the accumulation of fine ash in the Lake basin.

The limestone is later than the Newer Basalt: the Lake existed before, during and after the Mount Bullengarook scoria cone flow. The causes that lead to the formation of the Lake are seemingly similar, in some respects, to those responsible for the Duck Ponds Lake.

12.—WATCH HILL (?).

The records of the National Museum of specimens (Nos. 1895-6 and 2284-5) identified by McCoy (10) as *Nototherium mitchelli* Owen from " Murchill Station " have lost much of their value owing to the uncertainty regarding the locality. Concerning the specimens, which were obtained in 1865, the Museum Register gives the following information:—" Murchill Station (J. Bell) presented by—Dyson per Hon. Dr. Greeves." On August 26, 1865, McCoy published the following letter in " The Australasian ":—

> "I beg to announce in your columns a very interesting addition to the National Museum collection, which we owe to the kind offices of Dr. Greeves . . . The present addition is a small series of four specimens found at Murchill Station (belonging to Mr. John Bell) presented by Mr. Charles Dyson, of Market-square, Geelong, through Dr. Greeves . . ."

Although a number of authorities have been consulted and old papers and plans of the many properties owned by John Bell, a well-known Western District pastoralist, have been examined, all efforts to locate " Murchill " Station have been unavailing. Mr. J. Maxwell Bell of Golf Hill, Shelford, a member of the family, states that he has never heard of such a place in connexion with the pastoral holdings of John Bell and expressed the opinion that " Murchill " is Watch Hill, formerly owned by John Bell. There is little doubt that " Murchill " is an error: Mr. J. Maxwell Bell's opinion is probably correct.

That bone beds were known at an early date near Lake Corangamite to which the pastoral holding of Watch Hill had a frontage is shown by the following extract of a letter from E. C. Hobson (8) to R. C. Gunn of Launceston in 1854 on *Diprotodon* and mentioning an extensive bone deposit near the Lake:—

> "I have received a specimen of the distal end of one of the metatarsal bones of some large animal from (Lake Corangamite). The fragment is completely fossilised, and from a hard clay cliff on a salt lake beyond Lake Colac. The same person found a large bone, a femur, eight or nine inches in diameter at the upper end and 4 inches in the middle of the shaft."

The salt lake mentioned by Hobson was probably on the Watch Hill holding, which is shown on the 8 mile Geological Map of Victoria near the north-eastern shore of Lake Corangamite between Beeac and Cressy. It was wholly on the lava plain phase of the Newer Basalt and within its former boundaries were a number of lakes and swamps. The Woady Yalloak Creek flows through it.

Stratigraphical Position of the Diprotodontidae.

The containing beds of the *Diprotodontidae* have been dealt with in the foregoing pages in respect to the following localities:—

1.	North Melbourne ..	*Diprotodon australis* Owen.
2.	Footscray ..	*Diprotodon australis* Owen.
3.	Duck Ponds ..	*Diprotodon longiceps* McCoy.
4.	Limeburner's Point ..	*Diprotodon longiceps* McCoy.
5.	Lancefield	*Diprotodon australis, Nototherium* sp.
6.	Talbot	*Diprotodon longiceps, Nototherium* sp.
7.	Lake Colongulac ..	*Diprotodon* sp.
8.	Colac	*Diprotodon longiceps, D. australis.*
9.	Omeo	*Diprotodon* sp., *Nototherium victoriae* Owen, N. *inerme* Owen.
10.	Buninyong ..	*Nototherium* sp.
11.	Coimadai .. .	*Nototherium* sp.
12.	Watch Hill ..	*Nototherium mitchelli* Owen.
13.	Melton	*Notherium* sp.

The stratigraphical positions ascribed to the containing beds and their relationship to the succession of the fluviatile deposits as worked out by Keble and Macpherson are as follows:—

Age.	Maribyrnong River Cycles.	Maribyrnong River Phases.	Localities.
Recent	Present Cycle	Recent Maribyrnong Terrace	1, 2, 6, 9, 10.
Upper Pleistocene	Maribyrnong Cycle	Maribyrnong Flood Plain Braybrook Terrace	5, 7, 11, 12.
	Braybrook Cycle	Braybrook Flood Plain Keilor Terrace	
	Keilor Cycle	Keilor Flood Plain Vertical erosion	3, 4, 13?
Middle-Lower Pleistocene	NEWER BASALT (lava plain phase)		

The stratigraphical positions of 1, 2, 3, and 4 are considered accurate, 6, 9, and 10 approximate, and 5, 7, 11, and 12 are placed within wide limits.

All the species came from deposits newer than the lava plain phase of the Newer Basalt and all are of Upper Pleistocene age.

Habitat of the Diprotodontidae.

Including King Island, nine of the containing beds are of lacustrine origin, three are of fluviatile origin, and one is from a spring deposit. There is no doubt, therefore, that the Diprotodontidae preferred a terrain with lakes and swamps, or near rivers and springs. They were adapted to a mode of life in these surroundings and it is unlikely that they would be easily bogged, although this is the reason usually assigned for their remains being found in association with such deposits. Bogging casts a doubt on their adaptability to their environment; their feet were formed for an existence in swampy and marshy places, both hind and front feet were plantigrade, and their muscles, judged by the attachments, were strong.

Lake Callabonna, South Australia, where complete skeletons were found is described by E. C. Stirling (16) as a great flat clay pan covered at places with dunes and drift sand. The water is salt and there are a number of brackish springs issuing from its bed. The surface bed is a stiff yellowish clay containing much sharp sand, resting on a layer of unctious blue clay—the bone bed—about 2 feet thick, which overlies a bed of coarse sharp sand beneath which is a blue clay similar to the second bed. The position and attitude of the skeletons and the frequent approximation of the bones is, Stirling contends, strongly suggestive of death in situ after being bogged, which is supported too, he maintains, by the fact that the feet of the skeletons are most deeply buried. Conceding the possibility of their having been bogged, as Stirling suggests, it is difficult to understand why they were attracted by a salt lake The question presents itself, was Lake Callabonna salt when the animals were bogged? W. Howchin (9) states that the Lake is portion of the dead Frome River System that found its way [probably in the Pleistocene] to the southern coast but " it is doubtful whether any examples of this extinct fauna *Diprotodon,* etc., have been discovered in the older north to south river channels." The saline conditions are a result of a change of climate to the present arid conditions—a change from a wetter and fertile period to the present aridity G. Scoular (15) states: " as to the appearance and extension of the *Diprotodon australis* and similar congeners . . it was a greater annual rainfall which Australia enjoyed that ushered in these creatures upon the scene A greater rainfall implies that a more exuberant vegetation than we now possess was spread over the landscape, and following the law of evolution, a race of animals in every way more powerfully developed is evolved to utilize it "

Much the same problem arises in connexion with the remains found in Victoria near salt lakes such as those in the Western District. It is true that none of these remains have been definitely associated with saline deposits, but the lakes are now salt: were they always so? Previous to the present period of small inflow, insufficient in most cases to keep the lake from becoming salt and periodically drying up was there a wetter climate during which there was a greater inflow supplying the lakes with sufficient water to balance evaporation—a period when their waters were fresh or perhaps brackish? If so did this period coincide with the last glacial period? It is an interesting fact in this connexion that the North Melbourne and Footscray beds containing *Diprotodon* were according to Keble and Macpherson deposited at the close of the last glacial period (W3).

The probable habitat of the *Diprotodontidae* is well pictured by Mr. J. Graham Haines in his letter (*infra*) describing Egg Lagoon, King Island, in its undrained state. King Island has been affected less by the arid conditions of the mainland and Egg Lagoon must have represented a close approach to the natural habitat of these marsupials.

Occurrence of Diprotodon on King Island.

A record of *Diprotodon* from King Island not only fixes the southernmost limit of its migration—it is not found in Tasmania —but gives us some idea when the land bridge connecting Australia with King Island, and incidentally Tasmania, was broken.

In 1927 the National Museum received from Mr. J. Graham Haines a molar (No. 14403) of *D. australis* from Egg Lagoon, King Island, from what is recorded as a sub-Recent Deposit. This is the only record of *Diprotodon* south of the mainland; Scott and Lord (14) have, however, recorded *Nototherium victoriae* Owen from "swamp lands" on the Island.

Mr. Haines's information as to the precise locality is given in the following excerpts from his letter of June 19, 1944, which also contains an instructive description of Egg Lagoon in its undrained state:—

> "Quite a lot of teeth and jaw bones with teeth in them were found by men I have employed in excavating a drain through my property on Egg Lagoon in the north of King Island. In a distance of about a quarter of a mile, teeth and jaw bones were found in three different spots . . . The allotment on which the teeth were found is a 500-acre block in the name of J. Haines, 34/28. To the west of this block you will see it is joined by two blocks, one in the name of Holland and Haines, and the other in the name of C. Wilshire. Take the boundary of these two blocks which is the main Egg Lagoon drain, extend it half a mile, just a shade south of due east, and you will have the approximate place where the teeth were found. The drain was approximately 4 feet deep. The tooth was found in clay underlying rich black swamp soil.
>
> Egg Lagoon (the name is misleading) before it was drained was an area of low country that was under water during the winter and early summer . . . it grew the usual plants found on shallow swamps; it was soft and boggy at all times, particularly where it joins the sand and limestone country to the west. To the east, the land was slightly higher and covered with very big Paper Bark Ti Tree; it was in this country that the teeth were found. Before the drain was put through, there was more or less a natural water course, not washed out or anything, just a foot or so lower than the rest of the flat; it was covered with the same big Paper Bark Ti Tree and could not be picked out till the levels were taken . . ."

The fauna and flora of King Island is Tasmanoid, not Australoid. It is probable that the break of the land bridge connecting it with Tasmania occurred late in the subsidence of Bass Strait, and the fauna and flora has changed little. *Diprotodon* is a continental form and, since it has not been found in Tasmania, must have migrated to King Island by a land bridge connecting that Island with Australia. A reconstruction of the floor of Bass Strait from the bathymetrical contours indicates that this land bridge joined the Island on its east coast, the connexion being through the Mornington Peninsula on the mainland, it is improbable that there was ever a connexion through Cape Otway The Mornington Peninsula King Island land bridge was intact when *Diprotodon* first appeared in Victoria, i e in the early Upper Pleistocene or late Middle Pleistocene

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[PROC. ROY. SOC. VICTORIA, 57 (N.S.), PTS. I.-II., 1945.]

ART III.—*Note on the Age and Palaeogeography of the Brown Coal Deposits of Gippsland, Victoria.*

By IRENE CRESPIN, B.A.

[Read 9th November, 1944; issued separately 10th December, 1945.]

Contents.

INTRODUCTION.
BORES FROM WHICH SAMPLES HAVE BEEN EXAMINED.
DISTRIBUTION OF FOSSILS IN THE BORES.
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PROBABLE AGE OF THE BROWN COALS AND THE ORIGIN OF THE MICRO-FAUNA CONTAINED THEREIN.

Abstract.

Marine micro-fossils including foraminifera, bryozoa and ostracoda were found in the lignitiferous beds referable to the Anglesean Stage (Middle Miocene), in deep bores in East Gippsland. Later they were discovered in lignitiferous material from bores drilled to prove the extent of the bauxite in the parishes of Mirboo and Budgeree and of the brown coal deposits in the parishes of Loy Yang, Maryvale and Hazelwood. Based on stratigraphic evidence provided by these fossils, it is suggested that the brown coals of the Yallourn formation accumulated during the Middle Miocene, Upper Miocene and probably basal Lower Pliocene.

Introduction.

Following the record by the writer (1943) of a micro-fauna in the lignitiferous clays and sandstones underlying the marine deposits in numerous deep bores in East Gippsland, it was decided to investigate the lignites and sediments associated with them, in the Traralgon, Morwell, Mirboo, and Budgeree areas.

A series of bores has been drilled by the Commonwealth and Victorian Governments in the Mirboo and Budgeree areas to prove certain of the bauxite deposits there. These bores revealed that, in places, lignites are interbedded with the clays and sands which overlie the bauxite. A microscopic examination of samples of this lignitiferous material showed the presence of a small micro-fauna consisting of minute foraminifera and fragments of bryozoa, indicative of Middle Miocene to lower Upper Miocene age.

In view of this discovery, the State Electricity Commission of Victoria was asked by the Mineral Resources Survey to supply samples of the Yallourn Formation (Crespin, 1943) met with in bores put down to test the brown coal deposits in the Morwell and Traralgon districts. The Commission kindly complied with this request and samples have now been examined from bores in the parishes of Maryvale, Hazelwood, and Loy Yang. As a result a micro-fauna has been found. In preparing these samples for micro-examination every precaution was taken to avoid the inclusion of any adventitious material. That this fauna is indigineous to the lignitiferous beds is supported by the similarity of forms and by the manner of preservation of the fossils.

Bores from which Samples have been Examined.

(1) BORES TO PROVE THE BAUXITE DEPOSITS.

PARISH OF MIRBOO.

(*a*) Bore No. 27, from 26 feet to 36 feet, and 14 feet above the bauxite.

PARISH OF BUDGEREE.

(*b*) Bore No 15, from 105 feet to 110 feet, and 15 feet above the bauxite.

(*c*) Bore No. 16, from 103 feet and 26 feet above the basalt. (No bauxite was recorded from this bore).

(*d*) Bore No 18, from 89 feet to 90 feet, and 14 feet above the bauxite.

(2) STATE ELECTRICITY COMMISSION BORES TO PROVE BROWN COAL.

PARISH OF HAZELWOOD.

(*e*) Bore No 31 at depth of 335 feet (Mr. J. M Bridge of the State Electricity Commission notes that this sample is apparently from below the Morwell No 1 seam)

PARISH OF MARYVALE (MORWELL).

(*f*) Bore No 153, from 238 feet to 240 feet below surface. (This sample is 125 feet above the Morwell No 1 seam and is probably in the Yallourn seam — J M.B.).

(*g*) Bore No. 155 —First sample at 546 feet below surface. (8 feet below Morwell No. 1 seam, which is 500 feet thick at this locality. Sample was taken between two seams of coal each 3 feet thick.— J.M.B.).

Second sample at depth of 552 feet (14 feet below Morwell No 1 seam and 14 feet above No 2 seam, which is here 189 feet thick —J.M.B).

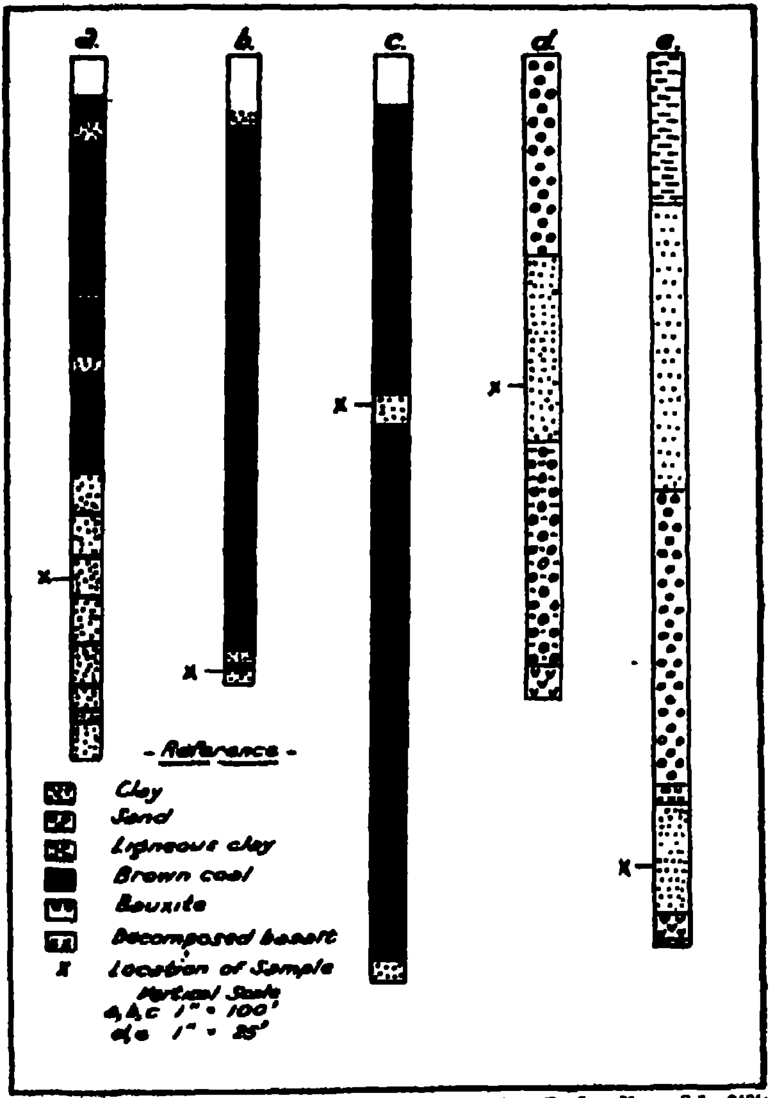
(*h*) Bore No 169, from depth of 312 feet. (86 feet below Yallourn seam and 30 feet above Morwell No. 1.— J M.B)

(*i*) Bore No 171.—First sample from 363 feet to 364 feet below surface (Immediately below Yallourn seam, which is here 301 feet thick.—J.M.B.).

Second sample 558 feet to 560 feet below surface (17-19 feet below Morwell No. 1 seam, which is 78 feet thick at this locality —J.M.B.).

Parish of Loy Yang (Traralgon).

(*j*) Bore No. 84, from 26 feet below surface.
(*k*) Bore No. 86, from 597 feet below surface.
(*l*) Bore No. 92, from 193 feet below surface.
(*m*) Bore No. 96, from 99 feet below surface. (26 feet below a 36-ft. seam, which probably corresponds to the Yallourn seam.—J.M.B.).



Text Fig.—Diagrammatic sections of bores. *a.* No. 109, Ph. Loy Yang, S.L. 240'; *b.* No. 31, Ph. Hazelwood, S.L. 235'; *c* No 92, Ph. Loy Yang, S.L. 200', *d.* No 27, Ph. Mirboo, S.L. 650'; *e.* No. 13, Ph Budgeree, S.L. 1050'.

(*n*) Bore No 103 at depth of 300 feet

(*o*) Bore No 109—First sample from 257 feet, second sample at 295 feet below surface (65 feet below the last major seam met It probably corresponds to an horizon immediately below the Morwell No 2 seam—J M B)

Distribution of Fossils in the Bores.

The following table lists the fossils noted in the bores detailed above The letter designations used in the table are the same as those given in the foregoing list —

Fossils	Bores														
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
FORAMINIFERA—															
Anomalina glabrata Cushman			x			x									
Anomalina sp 1					x										
Astrononion australe Cushman	x														
Cibicides cf victoriensis Chapman Parr & Collins							x								
Cyclammina sp															x
Eponides sp	x	x	x	x			x	x		x		x			
Elphidium crespinae Cush		x													
Elphidium sp	x														
Globigerina bulloides d Orb				x			x								
Globigerinoides trilobus (d Orb)	x														
Globorotalia cf canariensis (d Orb)	x														
Lagena sulcata (W & B)			x												
Marginulina glabra d Orb							x								
Planulina wuellerstorfi (Schw)	x														
ANTHOZOA—															
Mopsea tenisoni Chapman		x	x	x											
BRYOZOA—															
Cellaria sp															x
Crateropora patula (Waters)							x								
Filisparsa orakeiensis Stol				x											
Hornera sp			x						x						
Idmonea milneana d Orb				x											
Membranipora macrostoma (Reuss)					x										
Retepora rimata Waters				x											
Retepora sp											x				
Scuticella sp				x											
Bryozoa indet				x	x		x	x		x					x
OSTRACODA—															
Aglaia clavata G S B	x														
Alatacythere praeantarcticum (Chapman)	x														

Samples from Loy Yang Bores 96 (m) and 133 (n) contain ossils

Notes on the Fossils.

The majority of the fossils listed above are poorly preserved many of the bryozoa are indeterminate The fine pores are frequently filled with minute particles of lignitiferous material

The most important foraminifera of zonal value found in the above bores are *Cyclammina* sp and *Anomalina* sp 1, the former being characteristic of the Anglesean Stage (Middle Moicene) and the latter of the Mitchellian Stage (Upper Miocene) (Crespin, 1943)

Cyclammina is represented by several small, moderately well preserved tests in Loy Yang Bore No 109 at 295 feet The Anglesean Stage as represented in bores in East Gippsland, where it underlies rich fossiliferous marls referable to the Janjukian Stage, is not typical of the deposit as found at the type locality at Anglesea in Western Victoria, and it is in consequence of this facies change that the writer (1943) instituted the term "Yallourn formation ' for the Gippsland equivalent She has given the stratigraphic range of *Cyclammina* from the Anglesean Stage up to the Batesford substage of the Balcombian Except for one record in Sector II (Providence Ponds), the occurrence of the genus in the Batesford substage is restricted to the deep bores in Sector IV (Ninety Mile Beach) In view of this extended stratigraphic range of the genus, it may be unwise to assume that the sample in which *Cyclammina* was found is definitely referable to the Anglesean, but from information available it seems that it came from an horizon low in the Yallourn formation

The species referred to as *Anomalina* sp 1 in the Hazelwood Bore No 31 at 335 feet has a restricted stratigraphic range In the Gippsland bores and in the Lakes Entrance Oil Shaft, the species does not occur in a downward direction below the top part of the Middle Miocene, i e the Bairnsdale substage of the Balcombian It is the characteristic species of the Mitchellian Stage (Upper Miocene) and ranges into the basal portion of the Kalimnan Stage (Lower Pliocene)

Cibicides cf *victoriensis* *Astronion australe* and *Elphidium crespinae* although typical of the Balcombian Stage in Gippsland as well as in other parts of Victoria, have an extended vertical range in Gippsland *A australe* is recorded from the Anglesean up to the Kalimnan, where it is fairly common in the basal portion *C victoriensis* and *E crespinae* range from the Anglesean to the Mitchellian, but their characteristic development is in the Balcombian

Joints of *Mopsea* are common throughout the Balcombian Stage in Gippsland

All the specimens of bryozoa are poorly preserved They are all chalky white in appearance and very fragmentary The assemblage of species is typical of the Middle and Upper Miocene deposits of Gippsland

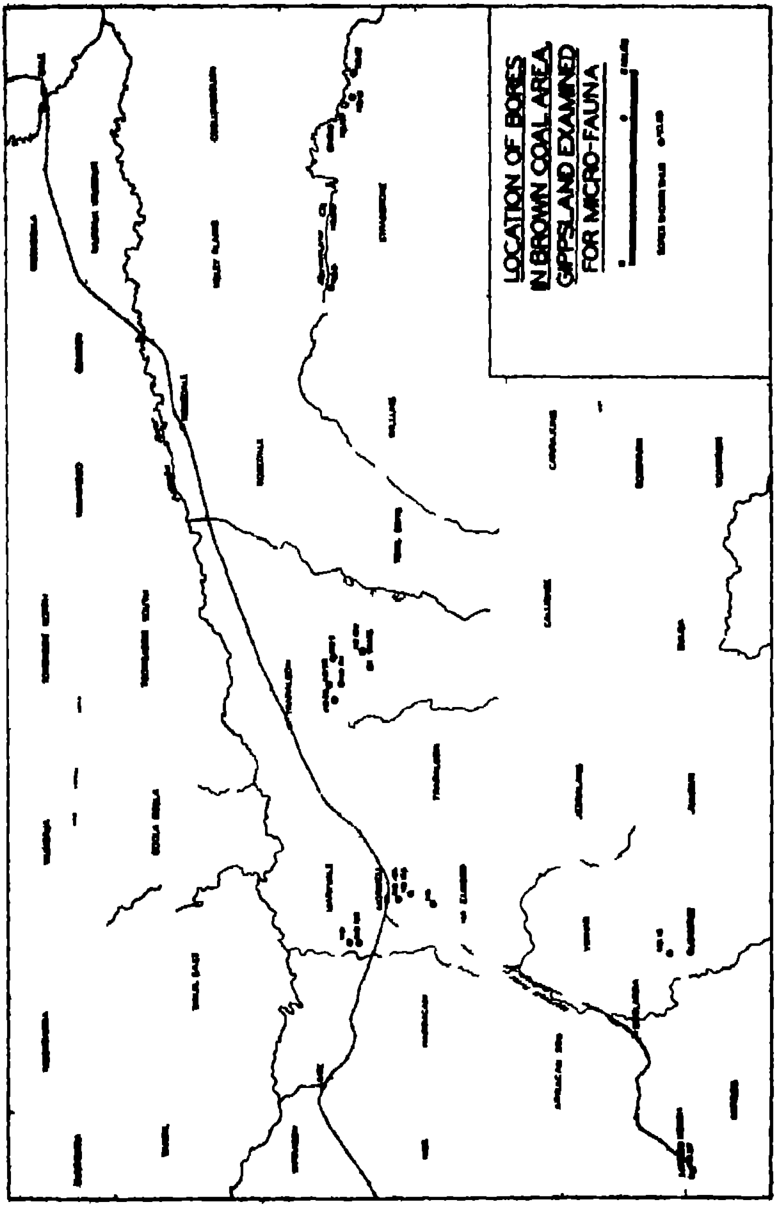
Probable Age of the Brown Coals and the Origin of the Micro-Fauna Contained Therein.

Consideration of the Tertiary stratigraphy, based on the examination of samples from the bores listed above and of numerous sections of deep bores east, south, and south-east of the brown coal deposits, suggests that the brown coals of Gippsland accumulated over a considerable period of time. The basal portion of the Yallourn formation is represented by the Anglesean Stage, which, east of a line running north from the western portion of Ph. Stradbroke through the parishes of Coolungoolun, Wurruk Wurruk, and Bundalaguah to Ph. Stratford, has been proved by boring to underlie the marine fossiliferous beds of the Janjukian Stage. West of that line there was apparently a period of accumulation of material in lakes which lasted from Anglesean times (Middle Miocene) until the close of the Upper Miocene (Mitchellian Stage) or opening of the Lower Pliocene (Kalimnan Stage). It is suggested that the brown coals accumulated during this period. During the deposition of the fossiliferous beds to the east, there was some oscillation of the sea-floor bringing about a rise in sea-level. The result was a slight flooding of the lakes to the west by waters containing a few marine forms which were subsequently deposited in the lignitiferous sands.

The above suggestion as to age of the brown coals is substantiated by the presence of the typical Anglesean foraminifer, *Cyclammina*, in the sample from Bore No. 109, Ph. Loy Yang, which is the most easterly bore to be examined and which is situated nearer than the other bores to the main Gippsland Basin described by the writer (1943), and the presence, in Bore No. 31, Ph. Hazelwood, of *Anomalina* sp. 1, which does not appear in the stratigraphic section until the top of the Balcombian stage and which ranges through the Mitchellian to basal Kalimnan.

It is estimated that the brown coals are about 1,000 feet thick in the Morwell and Yallourn areas, with the Morwell No. 2 seam representing the lowest horizon. Foraminifera typical of the Anglesean Stage are present (in the Loy Yang Bore No. 109) in the lignitiferous clays which underlie this seam. It is quite probable that certain seams of brown coal in this portion of the area may be correlated with those which occur in many of the deep bores south and east of Sale. In these bores, seams of brown coal were encountered in the Anglesean Stage at considerable depths below the marine fossiliferous beds referable to the Janjukian. A seam 60 feet thick was present in the Sperm Whale Head Bore (Ph. Poole Poole) between the depths of 2,739 and 2,789 feet; 90 feet of brown coal were recorded from the Lake Kakydra Bore (Ph. Nuntin) between 3,041 and 3,131 feet; seams of varying thicknesses occurred in the Holland's Landing Bore (Ph. Bengworden South) and in the Sale Bore (Ph. Wurruk Wurruk). A micro-fauna was found throughout the Anglesean in all these bore sections.

In the lignitiferous clays and sands from bores in the Mirboo and Budgeree areas and in all bores examined in the Morwell and Traralgon areas, except Loy Yang No 109 the micro fauna is typically Balcombian and Mitchellian



Information derived from the Victorian Boring Records and personal investigation of many bores in the area, indicate that no marine sediments as developed in the Janjukian, Balcombian, and Mitchellian Stages east of a line drawn north from No 3 Bore, Ph Darriman through No 8 Bore, Ph Stradbroke on Merriman's Creek, along the western boundary of Ph Coolungoolun to the La Trobe River, thence to the western portion of Ph Stratford, are known west of that line A geological section drawn in an east-south-easterly direction from No 8 Bore, Ph Stradbroke through other bores along Merriman's Creek to No 14 Bore, Ph Giffard, at Seaspray on the Ninety Mile Beach, a distance of about 20 miles, illustrates the gradual thickening, in that direction, of the marine Tertiaries No 8 Bore, Ph Stradbroke, reached the brown coal at 3 feet below the surface, after passing through a few feet of the "Torrent Gravels" of Gippsland No 9 Bore, in the same parish and about 1½ miles to the east of No 8, penetrated the marine fossiliferous beds (probably Janjukian in age) at 32 feet and struck brown coal at 222 feet The thickness of the marine beds increases rapidly east of this bore, until in No 14 Bore, Ph Giffard, they had not been bottomed at 1,600 feet when drilling ceased, the bore then being in beds referable to the Batesford substage of the Balcombian

The country north of No 8 Bore, Ph Stradbroke to the La Trobe River and west through the parishes of Holey Plains and Rosedale to Moe has been intensively drilled to prove the extent of the brown coals, but no marine fossiliferous beds have been encountered

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The diagrammatic sections of bores shown in Text-figure 1, have been compiled from bore logs supplied by the Mineral Resources Survey Canberra and the State Electricity Commission of Victoria

A map showing various parishes in which the bores examined for microfauna are located, is attached The bore sites in Ph Stradbroke mentioned in the text, are also included

[PROC. ROY. SOC. VICTORIA, 57 (N.S.), PTS. I.-II., 1945.]

ART IV.—*Australian Ambrosia Fungi.*

(*Leptographium Lundbergii* Lagerberg et Melin, and *Endomycopsis* spp. Dekker.)

By SHIRLEY WEBB

(communicated by Dr. Ethel McLennan).

[Read 9th November, 1944; issued separately 10th December, 1945.]

Abstract.

1. The fungus *Leptographium Lundbergii* and two species of sporogenous yeasts belonging to the genus *Endomycopsis* were isolated constantly from the tunnels of the Australian ambrosia beetle, *Platypus subgranosus* in Myrtle beech, *Nothofagus Cunninghamii* and two other Australian timbers.

2. The characteristic features of *L. Lundbergii* are described in detail and compared with those of ambrosia fungi studied by other workers The conclusion is reached that ambrosia fungi from different parts of the world belong to the same genus *Leptographium* and probably in many cases to the above-mentioned species. The first name associated with an ambrosia fungus was that of *Monilia candida* Hartig, but reasons are given why the fungus should not be placed in this genus.

3. The work of other authors connecting the conidial stage *Leptographium Lundbergii* with the ascigerous stage *Ceratostomella* is discussed and an affinity suggested between the Australian form and the species *Ceratostomella ips*.

4. The two species of *Endomycopsis* are described as Forms A and B. The frequent association of yeasts with wood-inhabiting beetles is mentioned and the question whether they serve the beetles directly as food or assist indirectly by stimulating the growth of the other fungus is discussed

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6. ISOLATION OF YEASTS FROM THE TUNNELS OF *Platypus subgranosus*.

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Introduction.

It has been recognized for the past century that beetles belonging to the group of wood-boring insects known as Ambrosia beetles, cultivate in their galleries a fungous crop upon which they, and their larvae, subsequently feed. The beetles themselves have received considerable attention and have been described accurately, whereas comparatively little mycological work has been done on the associated fungi

Specimens of the timber of myrtle beech, *Nothofagus Cunninghamii,* which had been attacked by the Ambrosia beetle *Platypus subgranosus,* were submitted to the Botany Department of the Melbourne University and many cultures were made from the wood immediately surrounding the galleries of the beetle, and resulted in the constant isolation of one fungus and two types of sporogenous yeasts. The fungus was identified as *Leptographium Lundbergii,* Lagerberg et Melin, and the yeasts as species of the genus *Endomycopsis* Dekker. Cultures from the beetles themselves and from larvae taken from the galleries also gave the same forms.

Isolations from the galleries of the beetle in two other Australian timbers, Mountain Grey Gum, *Eucalyptus goniocalyx* and Mountain Ash, *E. regnans,* helped to confirm the constant association of *Leptographium Lundbergii* and the *Endomycopsis* spp. with *Platypus subgranosus.*

Method of Isolation.

In making isolations from the beetle galleries, a block of infested timber, preferably with larvae or beetles still present, was taken and sterilized superficially with mercuric chloride solution The block was then split with a sterilized tomahawk in order to expose portion of the gallery or tunnel. Small slivers of the timber at the blackened edge of the gallery were removed with sterile chisel forceps and transferred to malt agar plates. The plates were left in the laboratory at room temperature during the warmer months of the year, but during the winter were incubated at 25°C. Appreciable growth of the associated organisms took place within four or five days.

Account of Leptographium Lundbergii.

NOMENCLATURE.

Leptographium Lundbergii is the type species of the genus *Leptographium* Lagerberg et Melin, created and described by Lagerberg, Lundberg and Melin (14) for a fungus which they isolated from a trunk of *Pinus sylvestris* showing intense blue-staining. This organism is now known to be a common cause of blue-stain in conifers and it has also been recorded by Verrall (28) as a lesser staining fungus of hardwoods in America.

Lagerberg and Melin emphasized when they created the genus, as did Grosmann subsequently, that *Leptographium* was in all probability identical with the genus *Scopularia* Preuss. *Scopularia venusta* was the name given by Preuss (18) to a blue-staining fungus which he found on decorticated pinewood in 1851. No spore measurements or details were given and the conidiophores were apparently falsely pictured. They were shown to be branched in a penicillate fashion and the individual branches to be septated. However, the curious manner in which the bases of the branches were extended across the main stalk of the conidiophore in a collar-like fashion looks very unreal. Saccardo doubted the fidelity of the reproduction, and as the fungus was not found again, it seems better to adhere to the later genus *Leptographium* rather than to the somewhat uncertain *Scopularia.*

Goidanich (7), a later worker, preferred the use of *Scopularia* to *Leptographium* and transferred *L. Lundbergii* to that genus.

GROWTH CHARACTERISTICS.

On malt agar, the fungus is fast growing, covering a 9 cm. Petri dish in four to five days. At first, it is sparse and white with very long aerial hyphae. In an inverted petri dish culture, these aerial hyphae reach right down from the surface of the agar to the lid as fine strands. In the majority of cultures, the white mycelium soon acquires a rather powdery appearance due to the formation of abundant conidia

As the culture ages, the mycelium gradually darkens, while the medium changes colour more rapidly and passes through various shades of brown, from Brussels Brown, Raw Umber, and Cinnamon Brown to Fuscous Black or Chaetura Black (Ridgeway Colour Standards and Colour Nomenclature). The aerial hyphae tend to flatten out very soon with the collection of drops of honey-coloured liquid and the surface of the culture appears moist or even sodden.

After a period of time, varying from about two weeks to two or more months, round yellowish-brown yeasty spots, up to 5 mm. in diameter, appear in many though not all of the cultures, and it is in these that the typical conidia and conidiophores of *Leptographium* are found clustered together.

After subculturing for some time, more aerial mycelium may be formed and the surface of the culture is then quite woolly, losing its yeasty or sodden appearance.

As the cultures commence to change in colour and become brown, microscopic examination shows the formation of yellow to dark-brown hyphae, twisted in loose strands, both in the aerial and submerged mycelium. Very wide brown hyphae, 10μ or more in diameter, also make their appearance and are characteristic.

The conidia are hyaline and unicellular and are extremely variable in shape and size. Those formed in very young cultures are as a rule oval or nearly cylindrical and may be from about 2 to 16μ in length (fig. 1A). Those formed later on the mature conidiophores are usually somewhat truncate and less variable in size, the average for 100 conidia being 8·9μ by 5·3μ with a range from 4 to 15μ by 3 to 7μ (fig. 1B).

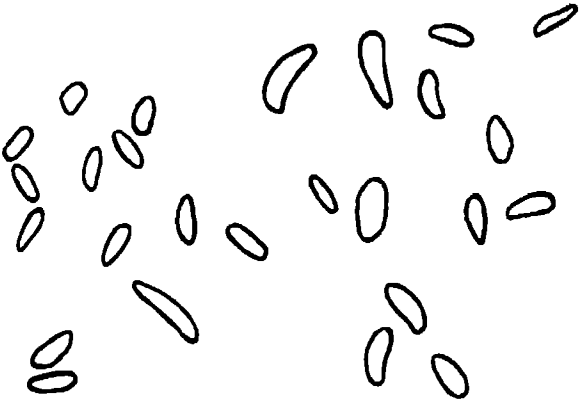


FIG 1A.—Conidia from a young culture of *Leptographium Lundbergii*. × 960.

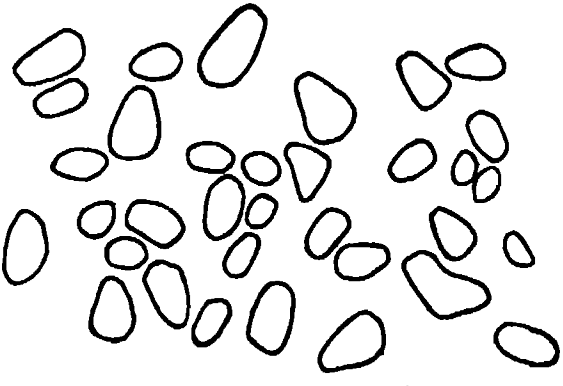
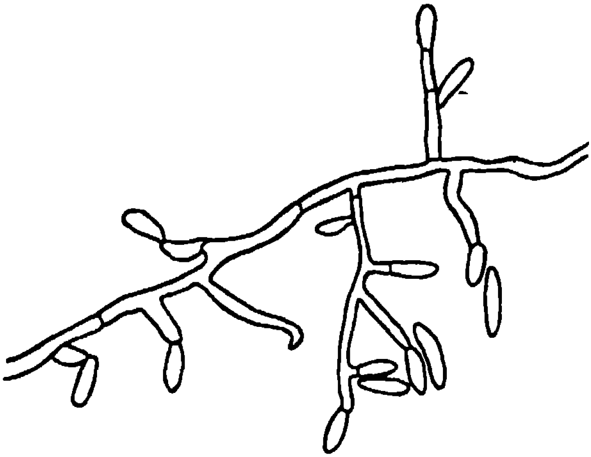


FIG 1B.—Conidia from a mature conidiophore in an old culture. × 960.

The mode of formation of the conidia varies considerably according to the age of the culture. At first, they are borne singly on the tips of the hyphae and on short branches along the main hyphae (fig. 2). The conidia tend to adhere together in mucous and form small round heads. This can be readily observed if the fungus is grown on a clear medium, when the spore heads



can be seen in situ through the agar (fig. 3). In this stage, a strong resemblance to the genus *Cephalosporium* is shown, and if the later mode of conidial development were not observed, the

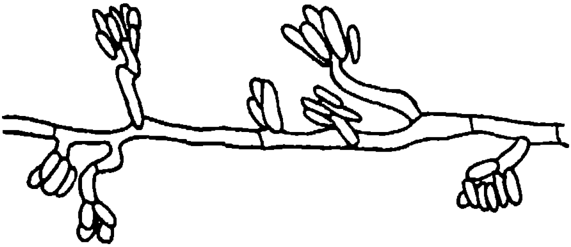


FIG. 3.—Cephalosporium stage of conidial formation. × approx. 720.

fungus could readily be placed in that genus. This stage will be referred to in future as the Cephalosporium stage. *Cephalosporium* Corda (Icon. Fung. III., II., 1839) is characterized by possessing unbranched conidiophores which arise as short lateral branches which are not swollen at the apex. The hyaline conidia arise singly at the tip of the conidiophore and are pushed to the side by the subsequent conidia without falling off, many holding together in a little mucous, forming a small spherical hyaline head.

As the culture ages, the Cephalosporium stage is passed, and conidia are constricted off from side branches which become more and more complexly branched, until eventually large brush-like heads are formed (figs. 4 and 5). The conidia are at first oval to somewhat rounded, but before being cut off from the conidiophore become more pear-shaped or truncate The branches of the conidiophore are septated and at first hyaline, but on maturing become brown in colour towards the base. The septations of the mature conidiophore are close together and at times give a distinct monilioid appearance. The conidia normally remain hyaline, but very occasionally individual ones may become yellow or brown in colour.

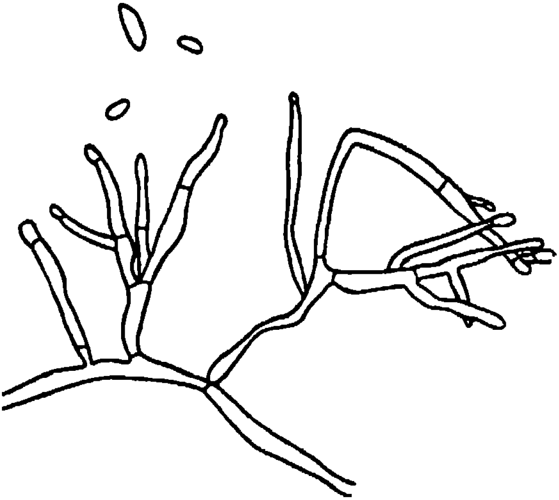


Fig 4 —Simple branched conidiophores × approx 720

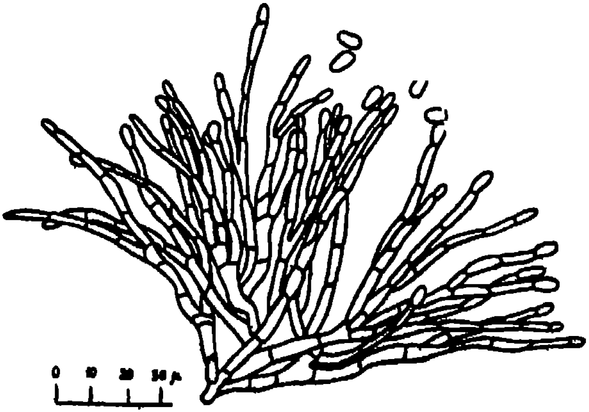


Fig 5 —Portion of a mature conidiophore × approx 480

The conidia frequently bud in a yeastlike fashion as soon as they are shed and produce a beaded or monilioid type of mycelium on the surface of the culture, giving rise to the yeasty or sodden appearance mentioned above. At times, this yeast-like budding is so profuse in a young culture, that the surface of the colony is flat and moist and faintly yellow or brown in colour and there is no formation of the long white aerial hyphae typical of most young cultures.

Isolations from the beetle galleries in Mountain Ash, *Eucalyptus regnans,* gave in addition to the typical fungus a much more slowly growing form of *L. Lundbergii.* This form was characterized by a complete lack of aerial mycelium and by the very early formation of typical *Leptographium* conidiophores in sulphur yellow mounds. The first formed conidia were more like the mature conidia in shape and size and not nearly as variable as those formed at first in cultures with more aerial mycelium.

APPEARANCE IN THE BEETLE TUNNELS.

The appearance of the ambrosia fungi in the beetle tunnels in the wood has been described by most authors as a palisade of monilioid chains of cells showing glistening white when young but discolouring with age.

When sections of the tunnels of the Australian ambrosia beetle in myrtle beech are examined under the microscope, a similar condition is seen. If examined closely, however, it will be seen that the palisade consists of fairly wide septated hyphae, which are light-brown at the base and gradually pale off to the tip where a single hyaline, truncate conidium is borne. The septations give the appearance of moniliform chains, but actually only a single conidium is carried at the tip of each septated hypha. This condition is illustrated in Plate IV., figs. 1 and 2, and if the fungal layer is studied and compared with the illustration of Leach *et al* (16) of the ambrosia fungus in the tunnels of the beetle *Trypodendron retusum* in *Populus tremuloides*, the two will be seen to be strikingly similar. At this stage, the ambrosia fungus in the tunnels resembles very closely the apices of the ultimate branches of the mature conidiophores of *Leptographium Lundbergii.* The actual branching of the conidiophores is obscured because of the dense growth of the fungus around the edge of the tunnel.

Since the beetles and larvae are cropping continually at the fungal layer, this complete condition of the apices of the conidiophores with their terminal conidia forming a continuous palisade is not often to be found. More frequently, the short wide hyphae are cut off to about the level of the first septum and are seen with jagged ends while the conidia lie loosely about their bases. An occasional long septated hypha complete with its terminal conidium projects forth into the cavity of the tunnel where it has been missed by the beetles. At other times less mature conidiophores are seen with narrower hyphae and more rounded conidia at the apex.

The wood adjacent to the tunnels of the beetles is distinctly blackened, giving the appearance that the tunnels have been made by plunging red-hot needles into the wood. The black stain does not spread more than about 1 mm. in a transverse direction or horizontal direction but may extend 10 mm. or more longitudinally from the edge of the tunnel. When sections of the blackened wood are examined, the wood vessels and fibres are seen to be densely packed with dark, much branched hyphae. The presence of these dark hyphae and the resultant staining of the timber around the tunnels lend support to the assumption that the ambrosia fungus is a wood-staining organism. Many yeast-like cells are also present lining the tunnels and at times it is difficult to distinguish between them and the immature conidia of *L. Lundbergii.*

The beetles and larvae keep the fungus closely cropped and the galleries remain clear in their presence. If, however, the timber is kept for a short time after the emergence of the insects, the conidia and yeast cells germinate and give rise to a headed monilioid type of mycelium. This stage is soon passed over and the tunnels rapidly become blocked with a tangle or plug of white mycelium.

COMPARISON WITH OTHER AMBROSIA FUNGI.

Thomas Hartig (11) was the first to recognize the fungal nature of the ambrosia and in 1844 gave the name *Monilia candida* to the ambrosia fungus of the beetle *Xyleborus* (*Bostrychus*) *dispar.*

In 1897, Hubbard (13) discussed the ambrosia beetles of the United States and gave illustrations and descriptions of their respective fungi. Although he made no attempt to name or grow them in culture, he pointed out that they were specific and that only the most closely related species of beetle had the same food fungus. His illustrations are interesting and informative. The long septated conidiophores which he pictured for the ambrosia fungus of the beetle *Xyleborus pubescens* and that of *X. celsus* show a strong resemblance to those described above from the galleries of the Australian beetle, *Platypus subgranosus.* Hubbard observed that an umber brown discolouration tinged the base of the clustered "stems" of the ambrosia of *X. celsus,* but that their terminations were pellucid and filled with colourless protoplasmic granules. This point increases the resemblance to the terminal branches of the conidiophores of *Leptographium Lundbergii.*

He described the ambrosia of *Xyleborus xylographus* as consisting of short erect stems terminating in spherical conidia and pictured the so-called stems each with three or four septa. He stated that the freshly grown fungus is as colourless as crystal but that it is usually more or less stained greenish-yellow, sometimes resembling a coating of sublimed sulphur. Rumbold (19) in a paper on the association of blue-staining fungi with bark beetles in pines, mentioned Hubbard's work on ambrosia beetles and she too noticed the resemblance to *Leptographium Lundbergii*, pointing out that this description of Hubbard's " reminds one of the greenish-yellow clumps of conidia, which later are honey coloured, that characterize the test tube cultures of *Leptographium Lundbergii*, Lagerberg et Melin." The ambrosia fungus of *Xyleborus pubescens* as figured by Hubbard, reminded Rumbold of the conidiophores of either *Ceratostomella pini* or *C. ips*, although she stated that his illustration did not represent them exactly. This point is of interest in view of work to be mentioned later which connects species of *Ceratostomella* including *Ceratostomella penicillata* and *C. ips* with the imperfect stage of *Leptographium Lundbergii*.

Hubbard was of the opinion that the ambrosia fungi were specific and that only the most closely related species of beetle cultivated the same food fungus. However, it is possible that he observed the same species of fungus in different stages and did not recognize the relationship between them.

Schneider-Orelli (22) gave a more complete account of the ambrosia fungus of *Xyleborus dispar*. He stated that the walls of the beetle galleries were lined with hyaline, thin-walled, septated hyphae which swell out at the apex into a sphere; at later stages these spherical cells could be seen in long chains. He mentioned that in the galleries of another species, *Xyleborus saxesent*, the cells remained single and were not seen in chains. According to Schneider-Orelli, the ambrosia fungus lost its monilial nature when grown in culture and became more truly mycelial. However, even the mycelial growth was characteristic, particularly with regard to the browning of the upper surface of the culture and the reddish-brown and ultimate black colouration of the medium. He did not observe a true spore stage in culture, and on this account did not give the fungus a definite name, not being completely satisfied with *Monilia candida* Hartig.

Three Californian Ambrosia beetles were described by Doane and Gilliland (5) in 1929 and brief references made to the ambrosia fungi associated with them. *Monarthrum scutellare* and *M. detigerum* on oak were found to cultivate a fungus which they thought was probably a species of *Monilia*. They stated that in culture on alfalfa agar " the conidiophores grow from the prostrate mycelium and these bear branching hyphae which form terminally continuous chains of conidia." As this is the extent of the description of the fungus in culture, it is difficult to compare it with forms examined by other workers.

Trotter (27) in 1934 examined the ambrosia fungus of a tropical *Xyleborus* species in the branches of *Brownea Grandiceps* from Ceylon. He observed a layer of short chains of sub-olivaceous, sterile, torulose, subglobose hyphae, 8-12μ in diameter, composed of two or more conidium-like segments of which the terminal one was the thickest. A second fungal layer above this consisted of a whitish mass of hyaline, variously shaped continuous conidia ranging from 8 to 4 by 35 to 7·5μ or even larger. When grown in culture, new conidia were produced of the type observed in nature, and, on the same mycelium, short branches with microconidia. Trotter considered the fungus to belong to an undescribed genus and named it *Ambrosiamyces zeylandicus* n. gen., n. sp. Leach was of the opinion that Trotter was dealing with a fungus completely unrelated to his or Hartig's ambrosia fungus. However, the chains of sub-olivaceous hyphae composed of two or more conidium-shaped segments, crowned by a layer of hyaline conidia are very suggestive of the picture presented by *Leptographium Lundbergii* in the tunnels of the Australian Ambrosia beetle, while the production of micro-conidia on short branches resembles the Cephalosporium stage of young cultures mentioned earlier, in which the first formed conidia are frequently very small and are seen in small heads. The possibility that Trotter was dealing with *L. Lundbergii* or a closely allied species does not therefore seem to be excluded.

More recent work on ambrosia fungus has been published by Leach, Hodson, Chilton, and Christensen (16). These authors gave a detailed description of the ambrosia fungus of two species of beetles, *Trypodendron betulae* on birch and *T. retusum* on aspen. These two beetles cultivate the same fungus which Leach and his co-workers considered to show enough resemblance to the ambrosia fungus of *Xyleborus dispar*, as described by Hartig and Schneider-Orelli to be placed in the same genus, though probably in a different species. On account of the confusion over the nomenclature of *Monilia candida*, they made no attempt to apply a new name, thinking that ambrosia fungi should be studied in more detail before their rightful place was decided. Pending further studies, they thought the fungi associated with the beetles *Trypodendron betulae* and *T. retusum* might be considered as strains of *Monilia candida* Hartig.

The ambrosia fungus of these *Trypodendron* species, when grown in culture, was at first hyaline but became brown with age and the medium was discoloured with a diffusible brown stain. At first sporulation was poor and only imperfect monilioid spores, that tended to remain attached and bud in situ, were formed. After repeated subculturing, variants that sporulated abundantly and consistently were obtained. The spores were hyaline and averaged 11·38μ by 10·09μ in size, with a range of 6 to 17μ in length and 6 to 14μ in width. No reference was made to branched conidiophores, but the description of the fungus otherwise corresponds well with that of *Leptographium Lundbergii.* The authors did not observe the large yellow to brown yeasty patches formed by the typical *L. Lundbergii* conidiophores in culture, but as these are often produced only after a period of two months or more, and sometimes not at all, it is not surprising that their formation was overlooked. The spore measurements come within the range of *L. Lundbergii.* The appearance of the *Trypodendron* ambrosia fungus in the beetle galleries in aspen and that of the Australian beetle, *Platypus subgranosus* in myrtle beech can be seen to be identical, if a comparison is made of the figure in the paper by the above-mentioned workers and Plate IV., figs. 1 and 2 in the present paper.

Verrall (30) made a number of new species for the ambrosia fungi which he found in constant association with species of *Platypus, Pterocyclon,* and *Xyleborus. Cephalosporium pallidum* is the name which he gave to the ambrosia fungus of the beetle *Xyleborus affinis.* His description of the fungus is as follows:—"On malt agar, colonies are moderately slow growing, reaching 9 to 14 mm. in radius in six days at room temperature. The margins are usually appressed and hyaline while the rest of the colony is covered with a thin layer of hyaline, fluffy aerial mycelium which often becomes appressed with age except for isolated tufts. Aerial mycelium may be entirely lacking. Occasionally a slight brownish tinge develops in parts of old cultures. Yellowish yeasty mounds develop in ageing cultures In the yeasty mounds, mycelium may be limited to pointed short celled hyphae projecting but shortly from the yeasty mass of conidia and monilioid cells. Compact helicoid hyphal formations were commonly observed in the filamentous mycelium.

Conidia germinate on malt agar by forming monilioid chains of cells which finally give rise to hyphae. Spore heads are formed relatively soon after germination. In culture, typical fruiting consists of cephalosporic heads of conidia protruding but slightly above the agar on erect or decumbent conidiophores. Conidiophores are generally unbranched and hyaline and terminate in one to ten or more hyaline unicellular conidia which are nearly spherical to slightly pear shaped, 7·6μ to 14·4μ long and 7·9μ to 14·0μ wide, averaging 10·8 by 10·4μ. When appreciable aerial mycelium occurs conidiophores elongate and branch. Sometimes the conidiophores are composed partly or totally of moniliform cells, particularly in the yeasty mounds. Occasionally buds were observed forming laterally on hyphae and monilioid chains of spores of irregular sizes and shapes were observed in the agar or protruding above it."

It has already been pointed out that cultures of *L. Lundbergii* pass through a Cephalosporium stage when young and that in this condition they might be mistaken for cultures of *Cephalosporium*. Moreover the mature septated conidiophores in the yeasty mounds have a distinctly monilioid appearance and are clustered so thickly together, that unless teased out and examined very closely, their complex branched nature is not readily observed. Altogether Verrall's description of *Cephalosporium pallidum* in culture shows such striking resemblances to *Leptographium Lundbergii*, that the justification for placing it in the genus *Cephalosporium* and his creation of a new species may be seriously questioned. However, his cultures are not available for comparison and it is therefore not possible to say that he was in reality dealing with *L. Lundbergii*. Verrall believed *Cephalosporium pallidum* to be related to *Monilia candida* Hartig. He pointed out, however that Schneider-Orelli, in describing Hartig's fungus, had made no mention of yellowish yeasty mounds or of cephalosporic heads.

Verrall created a second species of *Cephalosporium*, *C. luteum*, for the fungus which he found in association with the ambrosia beetle, *Xyleborus pecanis*. He did not observe yeasty mounds in cultures of his *C. luteum*, but he reports that the cultures were at first hyaline, though soon becoming sulphur yellow to light-brown, while the agar was stained a deep brown. Aerial mycelium was at first fluffy but became appressed with age. Spores were difficult to find, but when produced formed on simple or branched conidiophores, mostly singly, sometimes in heads of two or three spores. Once again, Verrall's fungus shows marked similarities to *L. Lundbergii*, and once more objection must be raised to his decision to place it in the genus *Cephalosporium*.

The ambrosia fungus associated with the beetles *Pterocyclon mali* and *P. fasciatum* was reported by Verrall to be *Monilia brunnea* n. sp. Cultures of this fungus were at first hyaline but became dark-brown with age and the original isolates were quite yeasty in appearance and consisted largely of monilioid chains of rounded cells that budded in situ. More mycelial growth developed with repeated culturing and small dark-brown mounds of monilial cells were seen in older cultures. These monilial cells were at times distinctly brown in old cultures and borne in simple or branched chains. . Verrall expressed the opinion that his *Monilia brunnea* was similar to, but not the same fungus as that described by Leach *et al* (16), for the ambrosia of the beetles *Trypodendron betulae* and *T. retusae* already described above. In spite of the similarities he preferred to create a new species for it. It can be seen, however, that all his points fit into the picture of *Leptographium Lundbergii*, the fungus described in this paper as the ambrosia of *Platypus subgranosus*, and it seems probable that he was in reality dealing with the same fungus.

CONNECTION WITH THE GENUS MONILIA.

The striking similarities in the ambrosia fungi described by authors from different parts of the world and discussed above, seem to indicate that they are all closely related or that they actually belong to the same species. In each case, the resemblance to *Leptographium Lundbergii* has been pointed out and the inference to be drawn is that the ambrosia fungus of Hartig, and those of Schneider-Orelli, Leach *et al*, Trotter and Verrall can all be linked up together with the former genus if not all with the species *L. Lundbergii.*

Leptographium Lundbergii is an extremely variable fungus and presents very different appearances at the different stages of its growth. The young cultures in the Cephalosporium stage with their fluffy aerial mycelium might easily be considered to belong to a different genus from the older stages with their appressed light-brown coloured mycelium, darkened agar and typical *Leptographium* conidiophores in the yellow or brown yeasty mounds. Some isolates produce more aerial mycelium and sporulate less frequently than others. It is therefore quite probable that it should have been described under various names by different workers.

The first name given to an ambrosia fungus was that of *Monilia candida,* by Hartig in 1844. However, Schneider-Orelli pointed out that since the work of Hartig, the name *Monilia candida* had been used by Bonorden (3) for a different fungus, the yeast-like form now so well known in the literature of fermentation. Bonorden was apparently ignorant of Hartig's earlier use of the name for the ambrosia fungus. *Monilia candida* Hartig remained completely disregarded for a considerable time, so that any discussion of *Monilia candida* in mycological text books almost always refers to the Bonorden fungus. Although Hartig's fungus actually would have prior claim, the name *Monilia candida* is in such common use for Bonorden's fungus that much confusion would arise in any attempt to change it.

But in any case, the use of the name *Monilia candida* for the ambrosia fungus seems to be excluded. The genus *Monilia* Persoon is characterized by having conidiophores with dichotomous grape-like or irregular, sparing or frequent branching, bearing at the tips of the branches or on little blunt teeth near the tips the simple or branched chains of hyaline conidia. The conidia of the Australian ambrosia fungus are borne singly, not in chains and therefore it should not be placed in the genus *Monilia.* Provided the assumption is correct that other workers have mistaken the septated terminal branches of the conidiophores of *Leptographium* for monilial chains of conidia, one would be justified in saying that none of the ambrosia fungi should have been placed in the genus *Monilia.*

Relationship of Leptographium with the Genus Ceratostomella.

Several workers have linked the conidial stage of *Leptographium* with the perfect stage *Ceratostomella*. In 1931, Grosmann (8) described a new species of *Leptographium*, *L. penicillatum* which she found, together with two or three characteristic yeasts, in constant association with the bark beetle *Ips Typographus* and sometimes with *Pityogenes Chalcographus* in the wood and bark of *Picea excelsa* in Saxon Switzerland and in Würtemberg. She distinguished *L. penicillatum* from *L. Lundbergii* by the form and size of its conidia and by the extreme length of its conidiophore. These features seem comparatively insignificant, particularly as the author herself stressed the variability in size of the conidia. Apart from these characteristics, her cultures agreed very closely indeed with the type species, *L. Lundbergii* as to growth and the manner in which the conidia were borne.

She was able to obtain in culture the perfect stage of the fungus which proved to be a new species of *Ceratostomella* and which she described in a later paper (9) under the name of *Ceratostomella penicillatum*. Single spore cultures from ascospores grew well and gave rise to the typical *Leptographium* stage The ascospores were oval or slightly curved and measured 6·5μ by 2·3μ, while the figures given for the perithecia were diameter of base, 250 to 300μ, length of neck 300 to 500μ, width of neck about 50μ.

Rumbold (19) studied the relation between bark beetles and blue-stain fungi and in a paper published in 1931 discussed two species of *Ceratostomella* which she found in constant association with these beetles *Ceratostomella pini* Munch was shown to be constantly associated with *Dendroctonus frontalis* and *D. brevicornis*, and *Ceratostomella ips*, n. sp. with *Ips calligraphus* and *Ips grandicollis* This new species, *Ceratostomella ips* was described in detail and further points about it given in a later paper (20). Although *Leptographium Lundbergii* was not actually mentioned as the conidial stage, the descriptions and illustrations show a very close resemblance to this fungus. Siemaszko (23) investigating the association of fungi with bark beetles in Poland also assumed that *C. ips* had a conidial stage of *Leptographium Lundbergii*. Describing the formation of the conidia of *C. ips*, Rumbold stated that "those first formed are small, sometimes 2 by 1μ. They are hyaline and obovoid. Later they form on simple conidiophores in a cluster that increases in number as the fungus ages. The conidiophores branch as they grow older until they look like small bushes In time the bases of the conidiophores turn brown, but the conidia-bearing tips and the conidia themselves remain hyaline. The later conidia range from 3μ to 10·5 by 1 to 3μ. They are usually clavate." Cultures were at first white but turned warm sepia very rapidly and finally jet black. Perithecia formed in culture were large and long-necked and were 55 to 301μ in diameter with an average of 198μ, 96 to 320μ in height, with an average of 206μ, and the length of the neck varied from 215 to 3,860μ, averaging 1,273μ. Ascospores had the shape of quadrangular prisms and ranged from 2·9 to 4·6μ by 1·2 to 2·8μ with an average size of 3·8μ by 2μ.

Usually there were no bristles at the ostiole of the perithecium although occasionally a few were seen, irregular both in number and length, measuring from 27μ to 45μ. Rumbold remarked that perithecia were formed in the galleries with their bases sunken in the gallery walls and that the beetles kept the necks well trimmed. After the beetles had emerged, the abandoned galleries were often filled with the protruding bristle-like necks of the perithecia.

Rumbold pointed out that the term "association" as used in the descriptions of the connection between *Ceratostomella pini* and *Dendroctonus,* and between *Ceratostomella ips* and *Ips* does not have the significance of the vital association that exists between the ambrosia beetles and the ambrosia fungi. The association appears to be a more casual one for the bark-boring beetles, which are not known to be dependent on fungi for food.

The conidial stage *Leptographium Lundbergii* was attributed by Rumbold (19) to another species of *Ceratostomella, C piceaperda,* which she found in association with the bark beetle *Dendroctonus piceaperda* on *Picea glauca* in Canada Perithecia were produced after about five months in culture and the ostioles were without bristles. Ascospores were hyaline and ellipsoid and measured 3·6 to 4·7μ by 1·9 to 2μ with an average of 4·3 by 2μ.

Lagerberg and Melin did not connect their newly-named fungus *Leptographium Lundbergii* with any of the species of *Ceratostomella* but considered it a distinct form They noted that Falck pictured a fungus exactly similar to it as the conidial stage of *Ceratostomella piceae,* but decided that the author was dealing with a mixture of fungi, *C. piceae* typically has *Cephalosporium* and *Graphium* conidial stages. MacCallum (17) in working with Scottish blue-stain fungi and *Ceratostomella piceae* in particular, also illustrated a branched conidiophore identical with that of *L Lundbergii,* but he made no mention of it except to note that a mixture of forms was present.

A species of *Ceratostomella* was found by Doane and Gilliland (5) to be associated with the ambrosia beetle *Gnathotrichus sulcatus* on Douglas Fir in California. Two distinct forms, the conidial and perithecial stages, were observed in the galleries

The conidial stage, which was not given a name and was incompletely described was replaced by definite black perithecia after the beetles had left their galleries. The perithecia were flask shaped and smaller at the base. No further morphological details were given and it is not possible to say which species of *Ceratostomella* the authors were examining.

The Association of Ceratostomella with the Australian Ambrosia Fungus.

On examining sections of the tunnels of the Australian ambrosia beetle in the timber of *Nothofagus cunninghami*, a cluster of fine bristles, 35 to 45μ long was seen occasionally to project into the space of the tunnel from the darkened mass of hyphae filling the wood vessels. In a few cases, these bristles were observed to belong to dark elongated perithecia which had formed in the vessels and which contained small asci with eight hyaline rectangular or prism-shaped ascospores (fig. 6). In addition, groups of ascospores were lying freely in the tunnels adjacent to these perithecia. The ascospores measured 5 to 7μ by 3 to 4μ with an average size of 5·9 by 3·5μ. It should be noted that the measurements only relate to a very small number of ascospores and that an average size for the fungus in question could not fairly be taken from them.

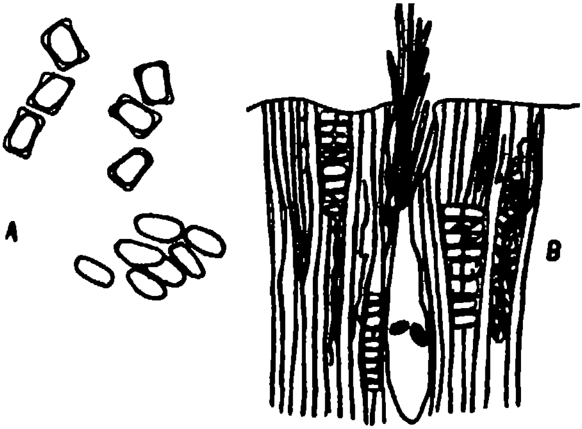


FIG 6.—A. Ascospores from a beetle tunnel. × 960.
B Bristles projecting into the tunnel from a sunken perithecium. × 160.

Perithecial measurements could not be made, but the peculiar prism-like shape of the ascospores, the diffluent asci and the presence of bristles associated with sunken perithecia in the tunnels suggest the possibility of an affinity with the species *Ceratostomella Ips* Rumbold. The fact that three species of *Ceratostomella* associated with wood inhabiting beetles have been described with a conidial stage of *Leptographium*, heightens the probability that the perithecia mentioned above really constitute a stage in the life history of the ambrosia fungus of the Australian *Platypus subgranosus.* Unfortunately all attempts to induce perithecial formation in cultures of *Leptographium Lundbergii* associated with the Australian ambrosia beetles, by the use of strongly acidified media and media rich in carbohydrates have so far been unsuccessful.

Isolation of Yeasts from the Tunnels of Platypus subgranosus.

As already noted two characteristic sporogenous yeasts belonging to the genus *Endomycopsis* Dekker were isolated constantly from the beetle tunnels in Australian timbers together with the ambrosia fungus. The two forms have not been placed specifically but have been designated Forms A and B. Stelling-Dekker (26) published a monograph on the sporogenous yeasts and created the genus *Endomycopsis,* placing in it many species which had formerly belonged to the genus *Endomyces.* The genus *Endomycopsis* is characterized by producing a true mycelium with septa together with yeast cells which show many-sided budding. In the genus *Endomyces* she placed those forms with true mycelium and yeast cells which only divide by transverse fission and not by many-sided budding. In both genera, the ascospores are as a rule hat shaped.

In Form A, asci are produced in whorls at the end of much branched septated hyphae and, after the ascospores have been shed, a new ascus is often seen to grow up inside the old one (see fig. 7 and Plate IV.). The asci are oval in shape and range

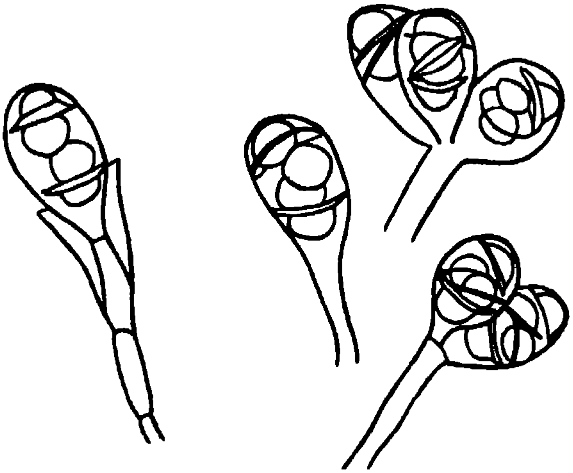


FIG. 7.—Asci and ascospores of Endomycopsis sp. Form A.
× approx. 720.

from 17·5 to 26μ by 11·5 to 20·3μ, with an average of 21·5μ by 13·9μ. They contain four ascospores which are large and very striking and which are produced readily on malt agar. They are prominently hat shaped, with the flange forming a definite brim. The measurements are as follows:—

	Range.	Average.
Diameter including brim	8–14 μ	11·8 μ
Diameter without brim	5–8 μ	7 μ
Depth	4–6 μ	5 μ

Only once has a complete ascus of Form A, with its four large hat-shaped ascospores been seen in the tunnel of the Australian ambrosia beetle in Myrtle Beech, although yeast cells have been very often observed.

The asci in Form B are considerably smaller and are more rounded than those of Form A (fig. 8). They may form in chains as well as in whorls on the branched septated mycelium They range from 6 to 9μ by 5 to 6μ averaging 7 by 5·5μ, and they contain four small inconspicuous hat-shaped ascospores. The ascospore measurements are as follows:—

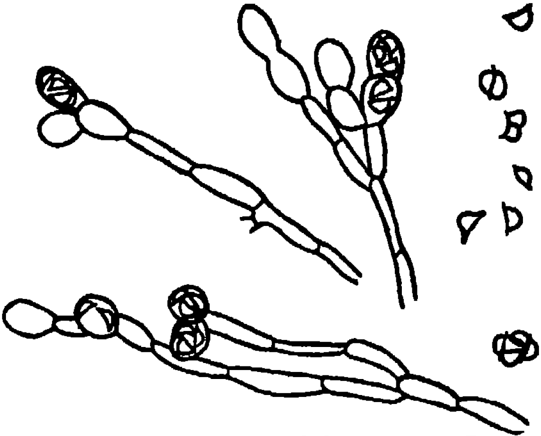


FIG 8.—Asci and ascospores of Endomycopsis sp Form B × 960.

	Range	Average.
Diameter including brim	3–5 μ	3·8 μ
Diameter without brim . ..	2–3·5 μ	2·9 μ
Depth	1·5–3 μ	2·2 μ

On malt agar, Form A produces a tough, much wrinkled buff-coloured colony with distinctly mycelial edges. In liquid wort, a gelatinous sediment but no pellicle is formed. The colony of Form B on malt agar is white and shining, somewhat wrinkled and fluted in the centre but smooth towards the outside with mycelial edges. With age, the colour becomes greyish. In liquid wort, growth is similar to that of Form A, producing a gelatinous sediment but no pellicle

The Association of Yeasts with Wood-inhabiting Beetles.

The association of yeasts with wood-inhabiting beetles is of common occurrence and has been reported by many workers.

Schneider-Orelli (22), whose study of the ambrosia fungus of *Xyleborus dispar* has already been mentioned, stated that yeasts were always present in the tunnels of the ambrosia beetles, but he regarded them merely as infections. He did not indicate whether they were always of the same type nor did he give any details.

In 1922, Beck (2), described a new species of yeast, *Endomyces bisporus,* which she found associated with the bark beetle *Ips typographus* on the bark of fir. As the name implies, the ascus only contained two ascospores. Stelling-Dekker transferred this yeast to the new genus *Endomycopsis,* calling it *Endomycopsis bisporus* on the grounds that the yeast cells showed many-sided budding and not just transverse fission. Verrall (3) in 1940 constantly isolated a similar yeast from the tunnels of the ambrosia beetle *Platypus compositus* in pecan, sweet-gum and swamp tupelo, and considered it to be the ambrosia fungus of that beetle. Apparently in ignorance of Beck's earlier work, he called the yeast *Endomyces bispora* n. sp., making no mention of Beck's species of that name or of Dekker's transference of it to the genus *Endomycopsis.*

Siemaszko (23) found members of the Saccharomycetaceae, mostly of a type closely resembling *Endomyces bisporus,* in constant association with *Ophiostoma* (*Ceratostomella*) *penicillata* and other species and the bark beetle *Ips typographus* on spruce in different parts of Poland.

Grosmann (8) in her work on the association of bark beetles and blue-stain fungi also isolated yeasts. They were of three types, a budding yeast with hat-shaped ascospores arising parthenogenetically, a second sporogenous one forming mycelium in addition to yeast cells, and a mycelium-forming asporogenous yeast.

Leach, Orr, and Christensen (15) found a characteristic yeast constantly associated with bark beetles and the blue-staining fungi in felled Norway Pine timber. On examining larvae they were often, although not always, able to demonstrate the presence of yeast cells in the intestine, while they were always present in varying amounts in the food contents of the intestinal tracts of freshly emerged beetles. However, the yeast cells did not show any signs of having been digested and used as food.

Studying the association of bark beetles and *Ceratostomella* spp., Rumbold (20, 21) in 1936 and again in 1941, noted that in making cultures from the timbers around the beetle galleries, yeasts were always the first organisms to appear, the blue-stain fungi only developing later. One of these yeasts was described by Holst (12) in a separate paper as *Zygosaccharomyces pini*, a sporogenous yeast forming hat-shaped ascospores but no mycelium. Holst was unable to produce evidence of any direct relationship between the yeast and the beetle. According to Rumbold, the yeasts seemed to have a stimulating effect on *Ceratostomella montium*, causing it to grow more vigorously and to fruit more quickly than in pure culture.

If, as she suggests, the yeasts tend to accelerate growth and sporulation of the fungus, there may be a definite significance in the constant presence of the *Endomycopsis* spp. in the tunnels of the Australian ambrosia beetles. It is conceivable that they stimulate the growth and fruiting of the ambrosia fungus and so increase the food crop for the beetles and their larvae. In addition to this, being rich in protein, they may serve directly as food for the beetles.

Support for this suggestion is to be found in the work of Guyénot (10) who showed that bacteria-free larvae of the fruit-fly *Drosophila ampelophila* may breed entirely on yeast. Under natural conditions, the larvae feed principally on yeasts and other micro-organisms. He reported that he had been able to raise fourteen generations of the fruit-fly in the absence of living organisms. The larvae were reared equally well on potato and living yeast, potato and dead yeast, and on dead yeast alone, but did not grow normally on sterile potato. These results were corroborated and amplified by Baumberger (1) who found that sterile larvae of *Drosophila* lived only five days and showed no increase in size on agar medium containing sugars, mineral salts, and ammonium tartrate as a source of nitrogen, but grew at a normal rate and pupated normally if the medium were infected with living yeasts. The larvae were also able to live on dead yeasts, showing that they were not dependent on the bi-products of fermentation but actually needed the yeasts as food. A concentration of 2 per cent. yeast was sufficient for normal growth. Baumberger concluded that insects inhabiting fermenting and decaying substrata of low protein content usually feed on the micro-organisms present and thus benefit by the power of fungi to extract, absorb, and synthesize many non-protein compounds.

Steinhaus (25), reviewing work on the microbiology of insects, stated that a type of symbiotic feeding on wood and similar substances is presented by the beetle *Anobium paniceum* which has special appendages of the mid-intestine containing Saccharomycetes in their cells.

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Description of Plate.

PLATE IV.

Fig. 1.—Photomicrograph of the fungal palisade lining a beetle tunnel. × approx. 95.

Fig. 2.—Portion of the same palisade under a higher magnification, showing ends of the compact conidiophores. × approx. 400.

Fig. 3.—Asci and hat-shaped ascospores from a culture of Endomycopsis sp. Form A. × approx. 1,800.

3 1 4

[Proc Roy Soc Victoria 57 (N S) Pts I II 1945]

Art V—*Botrytis Corm Rot of the Gladiolus—its Cause and Control*

By G C WADE B Agr Sc

[Read 14th December 1944 issued separately 10th December 1945]

Abstract

A serious corm rot of the Gladiolus caused by a species of *Botrytis* probably identical with *Botrytis gladioli* Kleb, is described The same fungus infects the leaves and flowers of the Gladiolus It overwinters as sclerotes which germinate producing conidia under certain conditions Infected flowers develop abundant conidia Corms are infected after digging the fungus entering through the cut stem end or the old corm It spreads along the vascular bundles and finally causes extensive rotting The disease may be controlled by dipping with Hortosan DP Zetan Corrosive sublimate or Aretan as soon after digging as possible The organism has a low optimum and maximum temperature and the disease may be avoided by digging early A number of popular varieties are resistant

Conidia are produced in artificial culture on certain media under the stimulus of light The fungus responds to increasing carbohydrate content in the presence of vitamins or plant extracts but not in their absence Starch accumulates in actively growing lesions but in arrested lesions the accumulated starch disappears and a suberinised layer develops between the healthy and diseased tissue The phloem tissue of infected vascular bundles is destroyed before the xylem tissue Infected corms develop an indicator pigment by reaction between the living corm tissue and the fungus

Introduction

In June 1940 specimens of Gladiolus corms exhibiting a soft rot condition were forwarded to the Department of Agriculture by a grower at Kalorama Victoria The condition did not resemble the Gladiolus diseases common in Victoria up till that time and investigations were commenced to determine its cause and control As will be demonstrated in this article the disease was found to be *Botrytis* Corm Rot

This disease was first described from Canada in 1927 (5) and has been mentioned in Canadian literature several times since that date (14 26) Drayton stated that it was common in Holland in 1929 (12) and according to van Poeteren (54) it is gaining ground in that country Moore (37) first noted the disease in England in 1927 He observed foliage symptoms in Holland in the following year It was recorded from Long Island New York in 1941 (11)

In 1934 Noble *et al* (40) recorded a leaf and stem blight caused by a species of *Botrytis* in New South Wales but as no mention was made of corm symptoms this appears to be distinct from the disease described here

Dimock (10) described an epiphytotic of a leaf and flower blight in Florida which he attributed to a species of *Botrytis* Tisdale W B (53) has subsequently cast doubt on Dimock s diagnosis and considers the blight was not caused by any organism but by physiologic causes The lack of corm symptoms and the doubt of the actual cause made it appear a different disease t that described here

From information obtained from growers the disease was probably present in Victoria for at least a year before specimens were submitted to the Department It was apparently introduced in imported corms somewhere about 1938 1939 Since the first record from Kalorama it has been recorded from other parts of the Dandenong Ranges the Geelong district the Ballarat district the Mornington Peninsula and the Metropolitan area of Melbourne The disease is also present in the coastal regions of New South Wales (correspondence with Drs C J Magee and Lilian Fraser of the New South Wales Department of Agriculture)

Losses caused by the disease have been considerable Some growers in the Kalorama district have lost over 50 per cent of the corms of susceptible varieties in years which have been favorable for the occurrence of the disease

Symptoms of the Disease.

All parts of the plant are affected by the fungus but from an economic point of view the attack on the corm is the most serious aspect of the disease

CORM SYMPTOMS

Corms may exhibit several types of symptoms but in the opinion of the writer these symptoms are successive stages in the attack of the fungus on the corm This view has also been suggested by Moore (37)

In the earliest stage of the disease only the core of the corm is attacked At this stage there are no obvious external symptoms and affected corms can readily be overlooked in an inspection of corms A close examination however shows a brown discolouration of the basal plate When the corm is cut the core region shows various stages of a brown rot condition (Plate V figs 4 7)

In later stages of the disease the rot travels along the water conducting vessels (Plate V figs 5 7) and it is possible for the corm to be extensively rotted internally without obvious external symptoms

When the disease reaches the surface of the corm it spreads rapidly producing a soft brown rot Finally the whole corm may be reduced to a soft, rotten condition Even at this stage of the disease, the symptoms may not be obvious till the bulb scales are removed However an infected corm will feel very soft when squeezed If the corm is held under humid conditions the fungus produces abundant white cottony mycelium on the surface of the corm This mycelium develops large black sclerotial masses (Plate V fig 3) Usually the sclerotes coalesce forming large coralloid bodies This stage is similar to that illustrated by Hicks (26) The mycelial growth and sclerote development usually occur on the surface of the bulb scales and between the bulb scales and the corm itself

Under other conditions which are not completely understood but probably include exposure to light and to less humid conditions than those which produce the cottony mycelial stage abundant conidia of *Botrytis* are produced on the surface of the corm However this stage is less frequently observed in Victoria than the cottony mycelium sclerotial stage

After extended storage the soft rotten corms gradually dry out to a mummified condition which usually bears abundant sclerotes on the surface (Plate V fig 2)

The extensive internal disorganization of the corm which in practically all cases involves the entire core region clearly differentiates this disease from other common Gladiolus diseases such as *Sclerotinia* corm rot *Septoria* corm rot and *Penicillium* rot *Sclerotinia* and *Septoria* produce very hard dry rots which do not usually penetrate very deeply into the corm *Penicillium* may produce an extensive soft rot but it can usually be traced to an injury on the surface of the corm and its commencement cannot be traced to the core region Thus a positive diagnosis of *Botrytis* corm rot can usually be made from a section of an infected corm

The symptoms of *Fusarium* Yellows (McCulloch 36) resembles the *Botrytis* disease in several respects In both diseases the core of the corm is attacked and the disease follows the vascular bundles This disease has not been recorded in Australia and the author has not had the opportunity of examining specimens but the presence of sclerotes on *Botrytis* infected corms would distinguish the two diseases The description in McCulloch's paper suggests that *Botrytis* also causes a softer type of rot than *Fusarium*

LEAF SYMPTOMS

The same fungus is capable of attacking the leaves of the plants Affected leaves usually show a large number of small brown spots which frequently have a reddish margin (Plate VI fig 13) The spots may coalesce causing larger brown areas and the leaves may die prematurely Conidia are produced on infected leaves under field conditions but much less abundantly than on infected flowers There is no evidence that this phase of the disease is of great importance under Victorian conditions as it rarely appears until after flowering when the plants are already senescent Until they are senescent Gladiolus leaves grow vertically and have a waxy surface This habit of growth would not favour infection from spores

FLOWER SYMPTOMS

Flowers frequently become infected in the field during periods of humid weather The fungus causes water soaked areas on the petals (Plate VI fig 16) These areas increase in size rapidly and finally cause the flower to collapse (Plate VI fig 17) Abundant conidia are produced on infested flowers (Plate VI fig 16) and this is important in the life history of this fungus which does not produce spores readily on most media

Flowers which are left in the field thus contribute a large proportion of the spore load of *Botrytis*

This attack also causes considerable direct loss through destruction of blooms

COLLAR ROT

The fungus occasionally causes collar rot of the growing plant under Victorian conditions The foliage of the affected plants becomes yellow and finally the whole plant dies When the affected plant is pulled up abundant sclerotes can be seen on the collar region of the plant (Plate VI fig 15)

This phase of the disease has not proved serious in Victoria and is usually due to planting infected corms It is apparently more important under English conditions (37)

The Causal Organism

ISOLATION

Numerous cultures from infected corms have been made using tissue platings on to potato dextrose agar and a species of *Botrytis* has been isolated consistently from the material

Isolations have not been readily obtained from infected leaves Moore (37) experienced the same difficulty He explained this by suggesting that many of the spots represent abortive infections by *Botrytis* However *Botrytis* has been isolated from large leaf spots formed by the coalescence of several smaller spots

Isolations have been successfully made from infested flowers, by plating small portions of infected material which had been surface sterilized with mercuric chloride on to potato dextrose agar Isolations have also been made from single spores on the flowers using Ezekiel s (17) modification of Keitt s method (31)

No difference could be detected between the characteristics of the organism isolated from the corms leaves and flowers

MORPHOLOGY

Mycelium—The mycelium of the fungus develops abundantly on infected corms held under moist conditions It is white in colour and is loose and fluffy in texture Mature hyphae are somewhat variable in size but average 12μ in diameter Young hyphae are much narrower and average about 4 to 6μ in diameter The growth on common artificial media is similar to the growth on the host When grown on potato dextrose agar slopes the mycelium develops profusely

Sclerotes—After several days growth on the corm or after about six days growth on potato dextrose agar, the mycelium near the substrata darkens and sclerotes develop These are at first creamy in colour but rapidly darken to black Frequently many sclerotes coalesce forming large coralloid masses Each individual sclerote is large in size and ranges from 1 mm to 6 mm in diameter The surface of the sclerotes is smooth

Macroconidia—Macroconidia are not formed abundantly on artificial media but develop abundantly on infected flowers less abundantly on infected leaves and occasionally on infected corms They are also produced from the sclerotes after several weeks storage under suitable conditions The conidiophores are brown in colour and of the typical *Botrytis* type (Plate V fig 9) The conidiophores are about 12–14μ in diameter The cells of the conidiophores are variable in length but average between 170–290μ This is in marked contrast to the length of the cells of conidiophores of a strain of *Botrytis cinerea* isolated from lettuce The cells of the conidiophores of the lettuce strain varied from 90–170μ The macroconidia are ovoid in shape and are 13–18μ (average 15μ) long and 11–12μ (average 12μ) wide They are thus considerably wider than the conidia of *Botrytis gladioli* as described by Klebahn (32) who gives the dimensions of conidia of that species as 8–15 × 3–6 (average 10 4 × 4 7μ) They agree with the dimensions of conidia from affected gladioli as given by Moore (37) who quotes the dimensions as 12–15 × 9 12μ (average 13 × 10μ) and with the dimensions given by B O Dodge and T Laskaris (11) who give the dimensions as 12 5 21 4 × 8 3–13 2 (average 15 8 × 10 5μ)

However it is doubtful whether this difference is sufficient to regard this *Botrytis* as a different species to *Botrytis gladioli* Kleb

Microconidia—Microconidia were not observed on natural media but develop freely in the depths of potato dextrose agar cultures over one month old The sporodochia appear macroscopically as olivaceous green aggregations of hyphae Microscopically the sporodochia are penicillate This form is common to many *Botrytis* species (Drayton 13) The microconidia are produced very abundantly and are spherical and about 2μ in diameter

No perfect stage of the organism has yet been observed, but the development of microconidia suggests that a perfect stage exists Drayton (13) states that, it is highly probable that this sexual mechanism is operative with perhaps slight modifications in all of the spermatia producing *Ascomycetes* including in the term spermatia microconidia of the type here described Groves and Drayton (21) have shown the perfect stage of *Botrytis cinerea* is a *Sclerotinia*

PHYSIOLOGY

The organism grows freely on most common media including potato dextrose agar and malt agar Its growth on Czapek's solution is not vigorous unless the solution is supplemented with vitamins On all these media conidial production is sparse under ordinary conditions Sclerotes are produced rapidly in cultures on artificial media if the organism has not been subcultured frequently If however the organism is subcultured frequently it eventually ceases to form sclerotes in culture The mycelium becomes yellowish in colour and a yellow pigment develops in the substratum

This behaviour resembles the dual phenomenon described by H N Hansen and W C Snyder (23)

In a later note (24) the same authors describe the existence of two forms of *Penicillium notatum* The C form is the normal conidial type which is maintained in that form if subcultures are made from conidia and care is taken to avoid carrying mycelium over during the transfer If mycelium is used in subculturing the fungus reverts to the non sporing M form which produces a yellow pigment in the substratum

As *Botrytis* sp produces conidia sparsely on artificial media subcultures have always been made with mycelium and this may explain the change in character of the fungus after prolonged subculturing However after repeated subculturing for over a year the organisms although changed in appearance was found to be still capable of infecting Gladioli

The influence of a number of factors on the growth of the organism was investigated

TEMPERATURE

Methods—The organism was grown in 200 cc Erlenmeyer flasks on a liquid medium of potato extract and glucose solution prepared in the same proportions as potato dextrose agar The solution was inoculated by adding a spore suspension of the organism The conidia were developed on autoclaved Gladiolus flowers which were inoculated from a recent isolate on P D A and then exposed to sunlight on the laboratory bench

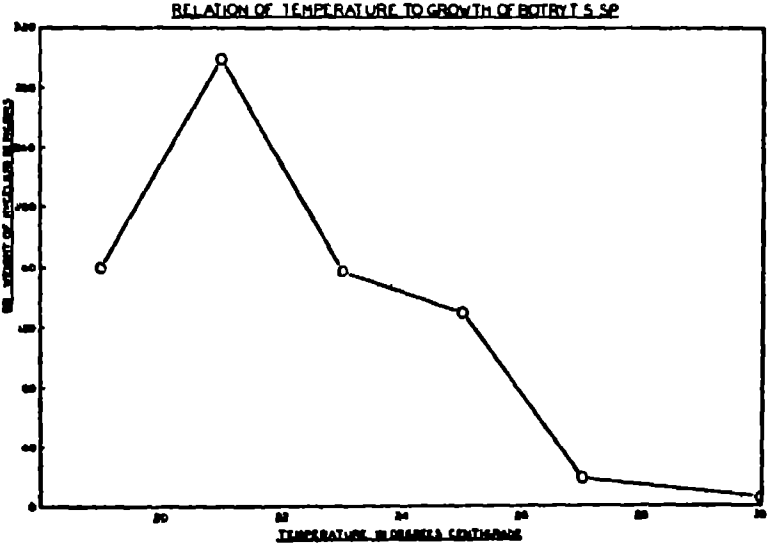
Six flasks were then incubated for ten days at each of the following temperatures —19°C 21°C 23°C 25°C 27°C and 30°C The fungus mats were then filtered off washed with hot water dried at 105°C and weighed

Results—The results are shown in Table I and are illustrated in Text fig 1 —

TABLE I

—	19 C	21 C	23 C	25 C	27 C	30 C
Weight of mycelium	grms 160	grms 299	grms 157	grms 13	grms 018	grms 006

The organism thus has an optimum temperature of about 21°C and a maximum temperature of about 30°C which is unusually low for most common fungi



This low optimal temperature is in agreement with field observations that the disease becomes most serious late in the season when the temperatures are low and the humidity high

Low temperatures favour other members of this genus L E Hawker (25) has reported that *Botrytis narcissicola* Kleb causes greater loss of Narcissus at cool or moderate rather than at higher temperatures

Brooks and Cooley (3) found that *Botrytis cinerea* had an optimum temperature of about 25°C The amount of growth fell rapidly as the temperature was raised above the optimum and only slight growth occurred at 30°C

LIGHT

Light has been found to stimulate the spore production of many fungi Hall (22) found that light stimulated the sporulation of *Sclerotinia fructigena* and when cultures on agar media in petri dishes were left exposed to sunlight on the laboratory bench alternate zones of vigorously sporing mycelium and sparsely sporing mycelium were produced The vigorously sporing zones were produced during the daytime and the sparsely sporing zones at night

G H Coons (7) found that pycnidia of *Plenodomus fuscomaculans* were only produced in the presence of light and C Ternetz (52) found the asci of *Ascophanus carneus* were produced under the influence of light

A Beaumont *et al* (2) found that conidia of *Botrytis tulipae* developed on the host less rapidly in low than high light intensities

W Reidemeister (45) found that blue light but not red light favoured the development of conidia of *Botrytis cinerea*

Method A—Cultures of the *Botrytis* on P D A in petri dishes were prepared and when the growth was well established half the dishes were removed from the incubator and placed on the laboratory bench

Results—Some conidia developed on the plates exposed to the light particularly at the edges of the cultures while no conidia developed on the unexposed plates in this experiment and they have only rarely been observed on cultures which have not been exposed to the light However sporulation was not vigorous even on the exposed plates and therefore light is not the only factor which induces sporulation in the field

A Beaumont *et al* (2) produced conidia of *Botrytis tulipae* by exposing P D A plates to light

Method B—Wheat grains were soaked over night in water and then 24 test tubes were half filled with the grains plugged and autoclaved They were then inoculated with *Botrytis sp* Twelve of the tubes were placed on the laboratory bench and twelve in an incubator with a glass front held at 23°C Half of the tubes on the bench and half of the tubes in the incubator were wrapped in brown paper to exclude light

Results—The tubes were examined after fourteen days incubation and it was found that the cultures exposed to the light on the bench and in the incubator had developed vigorously and abundant sclerotes had been produced In both cases the cultures from which light had been excluded had only developed sparse mycelial growth and very few small sclerotes The results are illustrated in Plate VI figs 19 22

Nicolaisen W *et al* (39) found that *Sclerotinia trifoliorum* behaves similarly and that darkness retarded both the mycelial and sclerotial development of that fungus

NUTRITION

Experiments have been conducted to determine the effect of increased carbohydrate and protein and the presence of vitamins on the growth of the fungus In preliminary experiments agar media were used and the diameter of the colonies determined as the criterion of growth This method is not entirely satisfactory for no allowance is made for the density of the growth of the colony

Method—Potato dextrose agar was prepared containing ½ per cent 1 per cent 2 per cent and 4 per cent of dextrose To P D A of each of these dextrose contents 0 per cent ½ per cent 1 per cent and 2 per cent of peptone were added Fifteen cc of the media were then poured into 10 cm petri dishes and inoculated at the centre with mycelium of *Botrytis sp* A uniform amount of inoculum was added by using a biscuit cutter 1 mm in diameter as described by Keitt (31) The plates were then incubated at 23°C in the absence of light After nine days incubation the plates were examined and the diameter of the colonies determined The experiment was conducted in quadruplicate

Results—The results are set out in Table 2 where the mean colony diameters are quoted —

Peptone Concentration	Dextrose Concentration			
	½ per cent	1 per cent	2 per cent	4 per cent
0 per cent	5 cm	7 cm	7 5 cm	10 cm
½ per cent	4 cm	6 5 cm	7 0 cm	10 cm
1 per cent	4 cm	6 0 cm	7 5 cm	10 cm
2 per cent	5 cm	6 0 cm	6 5 cm	10 cm

The most significant result of this experiment was the marked response to increase of dextrose concentration A similar response by *Botrytis cinerea* has been found by J L Weimer and L L Hartner (56) They found that the dry weight of the mycelium increased with increased concentration of dextrose up to 30 per cent dextrose and was then reduced by further increase in dextrose concentration

Peptone had no observable effect on the growth of the organism and apparently *Botrytis* sp does not require large amounts of protein for growth

UTILIZATION OF VARIOUS SOURCES OF NITROGEN

Method—Czapek's solution was prepared with the usual formula of—

Magnesium sulphate	0 5 grms
Potassium phosphate (K_2HPO_4)	1 0 grms
Potassium chloride	0 5 grms
Sucrose	30 0 grms
Water	1000 0 ml

The solution was then divided into six portions No nitrogen was added to one series and 0 2 per cent of sodium nitrate was added to another portion 0 123 per cent ammonium chloride 0 163 per cent of sodium nitrite 0 156 per cent of asparagin and 0 177 per cent of glycine respectively were added to the other four portions the nitrogen added being thus equivalent to 0 2 per cent of sodium nitrate 1 7 per cent of agar was then added to each solution and after autoclaving 15 cc of the various media were poured into sterile petri dishes They were inoculated as previously described and then incubated at 23°C for six days when they were examined and the diameter of the colonies determined There were four replicates of each treatment

Results—The results are shown in Table 3 —

TABLE 3

Nitrogen Source	Colony Diameter	Type of Growth
	cm	
Nitrogen free	10	Extremely sparse growth
Sodium nitrate	10	Normal growth
Ammonium chloride	8	Normal growth
Sodium nitrite	4	Flat yellowish growth
Asparagin	7	Normal growth
Glycine	7	Normal growth

These results indicated that sodium nitrate was the most suitable source of nitrogen for *Botrytis* sp S J Du Plessis (15) in experiments on the physiology of *Botrytis cinerea* found that the greatest weight of mycelium per unit of nitrogen consumed was on a nitrate containing media

Therefore sodium nitrate has been used as the nitrogen source in subsequent experiments.

These results demonstrate the unsatisfactory nature of colony diameter as a criterion since the diameter of the colonies on media with no nitrogen was greater than when ammonium chloride, sodium nitrite, asparagin or glycine were present, but actually the growth was extremely sparse and the weight of the colony would have been very much less than the weight of the colonies on any of the other media.

UTILIZATION OF CARBOHYDRATE IN A SYNTHETIC MEDIUM

Method.—Czapek's solution plus agar containing 1.5 per cent, 3 per cent, 6 per cent and 12 per cent of sucrose was prepared. The same technique as has been already described was used and the colonies were measured after six days incubation.

Results.—The results are shown in Table 4 —

TABLE 4

Sucrose Concentration	Diameter of Colony
%	cm
1.5	3.0
3.0	2.5
6.0	3.0
12.0	4.0

Thus the fungus did not respond to increased sucrose concentration. It was therefore obvious that potato extract contained some growth factor not present in the synthetic medium and without this factor the fungus did not respond to an increase in carbohydrate.

EFFECT OF VITAMINS ON THE GROWTH OF THE FUNGUS

In 1858 Pasteur (43) had shown that growth of lactic acid bacteria was stimulated by the addition of onion juice to the medium. In 1860 Pasteur (44) found that the development of yeast in a synthetic medium was markedly improved by the addition of organic substances present in natural materials. These observations of Pasteur were the first indication of the existence of growth factors.

The importance of vitamins for the growth of certain fungi was first demonstrated by Schopfer (47) in 1934. He found that *Phycomyces Blakesleeanus* required thiamin for growth.

Schopfer (48) lists the following ascomycetes requiring thiamin for growth —*Saccharomyces cerevisiae*, *Nematospora gossypii*, *Nectria coccinea*, *Sphaerula trifolii*, *Valsa pini*, *Helvella* *infula* and *Haplodermium pinestri* The importance of thiamin for these organisms was demonstrated by a number of workers who are quoted by Schopfer

The importance of pantothenic acid was found by Williams *et al* in 1933 (58) and nicotinic acid was shown to be essential for the growth of *Staphylococcus aureus* by Knight (33) in 1935

Biotin was extracted from egg yolk by Kogl and Tonnis (34) in 1936 and found to be still active on *Saccharomyces* at a dilution of 1 in 4 × 10

In 1939 Orla Jensen *et al* (41) showed that lactic acid bacteria required riboflavin for growth

A full account of the historical development of this subject is given by Schopfer (48)

In view of the known importance of vitamins to fungal growth an experiment was conducted to determine whether a mixture vitamins of the B complex either with or without biotin would supply the factor without which *Botrytis* did not respond to increasing dextrose concentration

Methods—Czapek s solution with the addition of 0 5 grams of calcium chloride but without sucrose was used as the base solution Heavy metals (iron copper manganese and zinc) were added to the base solution Solutions containing 0 5 per cent 1 per cent and 2 per cent of dextrose were prepared

Ten per cent by volume of potato extract prepared by boiling 20 grams of potato in 100 ml of water and filtering was added to one series

Members of the B complex of vitamins (thiamin riboflavin nicotinic acid calcium pantothenate and pyridoxin) were added to another series to give final concentrations of 1γ per 50 ml

These vitamins together with biotin concentrate to give a final concentration of 1γ per 50 ml were added to another series No addition was made to a fourth series of solutions

Forty eight ml of the various solutions were pipetted into 200 ml Erlenmeyer flasks and autoclaved at half an atmosphere for twenty minutes

They were then inoculated by adding 2 ml of a spore suspension of *Botrytis* with a sterile pipette The spore suspension was prepared from a culture on autoclaved gladiolus flowers To reduce the risk of carrying over vitamins from the flowers the spores were washed twice by centrifuging syphoning off the supernatant liquid with sterile capillary tubing and adding fresh distilled water

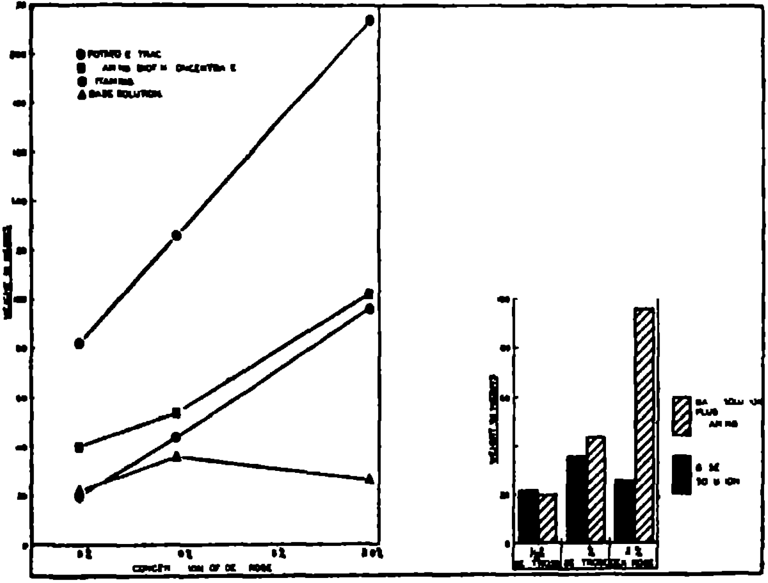
The flasks were then incubated at 25°C for ten days, when the mycelium was filtered off, washed with boiling water, dried at 105°C, and weighed

Results—The results are shown in Table 5 and are presented graphically in fig 2 —

TABLE 5

Addition to base solution	Dextrose Concentration % ½	% 1	% 2
No addition	022	036	26
B complex vitamins	020	044	096
B complex vitamins plus biotin conc	040	0 4	102
Potato extract	062	126	214

EFFECT OF VITAMIN B COMPLEX AND DEXTROSE CONCENTRATION ON THE GROWTH OF BOTRYTIS SP



The following statistical report on the results has been prepared by Dr H C Forster of the Victorian Department of Agriculture —

" A statistical analysis of the results has been conducted to determine (*a*) the significance of the difference between the respective treatments, (*b*) the significance of the difference if any, between the regression coefficients of the three treatments which included vitamins

Since the variation shown by the replicates of the different treatments varies directly with the mean value of the treatment, the analysis has been conducted not on the original figures but on a transformation based on log (100 x)

Comparison of the Different Treatments—Results on Basis of Log (100 x)

Base Soln			Base + VB			Base + VB + biotin			Base + Potato Extract		
½%	1%	2%	½%	1%	2%	½%	1%	2%	½%	1%	2%
34	54	40	30	64	98	60	68	1 08	92	1 10	1 34
43			64			79			1 20		

S E (between dosages) = 054 For significance differences must exceed 15
S E (between treatments) 038 For significance differences must exceed 09
F 1% both between main treatments and within main treatments

It is evident therefore that there are significant differences both between the various main treatments and except in the case of the base solution between the dosages of those treatments

Comparison of Regression Coefficients of Dosage Regression Lines of the Various Treatments

It is obvious that the regression line of the base solution is significantly different from the other three regression lines The base solution treatment has therefore been deleted from this analysis and a test conducted to see whether the other three regression lines differed one from the other

Analysis Treatment d/f	x	y	xy	$b = \frac{\Sigma xy}{\Sigma x^2}$	Errors of Estimate $y - \frac{(\Sigma xy)^2}{\Sigma x^2}$	d/f	M q
Base + VB 2	90	1 156	1 020	1 133	0 004	1	
Base + VB + biotin 2	90	662	0 720	0 800	0 086	1	
Base + Potato Extract 2	90	448	0 630	0 700	0 007	1	
					0 097	3	0 032
Total	2 70	2 266	2 370	0 878	0 185	5	0 037

$F = \frac{067}{062}$ which is not significant

It is apparent therefore that there is no significant difference between the regression coefficients of these three treatments

It should be noted that the regression coefficients of the above table are those of the transformed figures (References—Snedecor (51) and Cochran (6))

The results demonstrate that there is no response to increasing dextrose concentration when no vitamins and a purely synthetic medium is used When vitamins are added to the base solution however a marked response is obtained There was no significant difference between the gradients of the curves for increasing dextrose content when vitamins and biotin or potato extract are added to the base solution This suggests that vitamins are the main limiting factor in preventing response to increased dextrose The greater growth obtained with potato extract could be explained by the additional carbohydrate added with the extract and an extra growth factor is not necessarily present

Schopfer (48) in commenting on results obtained by Leonian and Lilly suggests that the effect of organic acids (succinic and fumaric) on the response of *Phycomyces* to thiamin is due to the addition of nutrients (carbon compounds and minerals) rather than to an additional growth factor In this case the response could not be due to minerals since pure mineral salts were not used and all the elements known to be important in fungal nutrition were added to all solutions

Little response to vitamins was obtained at low dextrose concentrations but a very marked response when 2 per cent was present (see fig 2) Burkholder and McVeigh (4) found that with 4 0 and 8 0 grams per litre of asparagin and thiamin at 1 × 10^{-6} Molar glucose was limiting up to quantities of 80 or 100 grams per litre

A definite response to biotin concentrate was obtained Crystalline biotin was not available for the experiment and unpublished data by Millikan suggests that the biotin concentrate used contains growth factors other than biotin

It is unlikely that all the vitamins added are essential for the fungus and further work will be conducted to elucidate this point

PRODUCTION OF CONIDIA

In the field conidia are produced abundantly on infected flowers less abundantly on infected leaves and occasionally on infected corms but as already stated in previous sections conidia are not produced readily on ordinary media

Newton (38) found that conidia of *Botrytis tulipae* were produced when the fungus was grown on tulip extract agar although this fungus does not produce conidia on barley meal corn meal or synthetic agar media Gladiolus dextrose agar was prepared in the same manner as potato dextrose agar However when the fungus was grown on this medium in the absence of light in an incubator at 23°C no conidia were produced When grown on this medium in the presence of light on the laboratory bench some conidia were produced but not more than on potato dextrose agar under the same conditions

As conidia are produced on naturally infected flowers, gladiolus flowers were placed in Erlenmeyer flasks and autoclaved They were then inoculated with *Botrytis* sp and placed in an incubator at 23°C They were then transferred to a laboratory bench exposed to the light In 21 days after the start of the experiment conidia had developed abundantly on the flowers

Hopkins (28) noted the vigorous sporulation of *Botrytis tulipae* on infected flowers and suggested this was due to the favorable moisture relations He therefore grew *Botrytis tulipae* on potato dextrose agar in petri dishes and allowed the medium to dry out and conidia were produced on these plates

Reidemeister (45) considered that the drying out of cultures or culturing on media of high osmotic pressure were the most important factors in inducing sporulation of *Botrytis cinerea*

An experiment was conducted to determine whether drying out of the medium or exhaustion of the food supply would induce sporulation of *Botrytis* sp

Method—One millilitre of potato dextrose agar was pipetted into each of twelve 200 ml Erlenmeyer flasks autoclaved and inoculated with *Botrytis* They were then incubated at 23°C for seven days The plugs of six flasks were then dipped into paraffin to prevent the drying out of the agar The remainder were unwaxed Three waxed and three unwaxed flasks were then placed on the laboratory bench where they were exposed to light and the same number of waxed and unwaxed flasks left in the incubator away from light

Results—After fourteen days it was found that conidia had developed on both sets of flasks which were exposed to light but no conidia had developed on either set kept away from light

A similar experiment was also conducted with gladiolus flowers gladiolus stems and cyclamen flowers and again it was found that conidia were produced on the materials in both waxed and unwaxed flasks which were exposed to light but not in the flasks kept away from light

These results indicate that both exhaustion of the food supply and drying out of the medium can induce sporulation provided the cultures are grown in the presence of light

The effect of impoverishment of food supply on sporulation has been observed with many fungi For example G H Coons (7) found that rapid fruiting of *Plenodomus fuscomaculans* could be induced by removing a strongly growing culture to a dilute nutrient solution or to distilled water It appears that factors which are unfavorable to continued vegetative growth are favorable to sporulation

It has been noted that, after preparing a spore suspension from spore-bearing flowers in Erlenmeyer flasks, sporulation is profuse This may be due to washing away nutrients when the suspension is prepared

Apart from sporulation which develops from the mycelium under the conditions described, conidia are produced from sclerotes on cultures on any common medium, after the cultures are several months old Plate V, fig 11, shows conidial production from a sclerote from a potato dextrose agar culture Conidial production has been observed from sclerotes in cultures which had been stored away from light, but conidial production occurs more rapidly in cultures exposed to light

Botrytis cinerea produces conidia from sclerotes in a similar manner (60)

Effect of the Fungus on the Corm.

HISTOLOGY

Sections were cut of corms in which the disease was active and of corms in which the disease had been arrested The usual method of paraffin embedding was used, except that 5 per cent of microcrystalline wax was incorporated in hard paraffin to prevent the paraffin forming large crystals and thus facilitate sectioning

In active lesions the middle lamella of the cells of diseased parenchymatous tissue had been destroyed and the cells greatly distorted The cell contents showed no definite structure but contained an accumulation of starch granules At the edge of diseased lesions there is usually a sharp line of demarkation between the almost completely disorganized diseased tissue and the surrounding normal tissue (Plate VII, fig 23) The mycelium of the fungus was abundant in the disorganized tissue and sometimes penetrated to a depth of several cells into apparently normal tissue

In some sections, however, there was a layer of cells containing a reduced number of starch grains between the infected tissue and the normal tissue (Plate VII, fig 24) The infected tissue contained an accumulation of starch granules and there was no suberinised layer at the edge of the healthy tissue It therefore differed from the histological structure of arrested lesions, which will be described later

As previously stated the disease travels along the vascular bundles The phloem tissue of the infected bundles is rapidly disintegrated and later the wood vessels are attacked and destroyed Plate VII, figs *26a* and *b* shows a longitudinal section through an infected vascular bundle The phloem tissue has been almost completely destroyed but the wood vessels still show fairly normal structure Hopkins (28) noted that ***Botrytis tulipae*** destroyed the xylem of infected tulips

Infected tissue of corms in which the disease has been arrested differ in several respects from those just described The severely infected tissue is similar to that in actively growing lesions but no starch granules are present It is surrounded by a layer of cells about 1 to 2 mm wide which have practically no cell contents and very few starch grains, but the cell walls do not show marked distortion This layer of cells only contains few hyphae of the organism At the edge of these cells there is a layer of rectangular suberinised cells and beyond that the tissue is normal (Plate VII fig 25)

The development of a suberinised layer around diseased lesions in tubers and corms has frequently been reported Hill and Orton (27) found that potato tubers infected with bluestem disease produce a layer of suberinised tissue around the infected tissue

MICROCHEMICAL TESTS

To determine the chemical changes in the diseased tissue a series of microchemical tests were conducted Fresh hand sections were used and methods described by Johansen (30) and by Hill and Orton (27) were employed for most of the tests

METHODS AND REAGENTS USED

STARCH AND DEXTRIN

The usual iodine test

SUBERIN

A solution of Sudan III in 95% alcohol

REDUCING SUGARS

The osazone test as described by Johansen

PROTEINS

The sections were stained for 24 hours in a saturated aqueous solution of picric acid

CELLULOSE

They were placed in a drop of iodine solution and a drop of 75% sulphuric acid was allowed to diffuse under the coverslip

METHYL PENTOSES

The sections were placed in one or two drops of acetone a drop of hydrochloric acid was added and the sections warmed for fifteen minutes

LIGNIN

The sections were placed in a 1% alcoholic solution of phloroglucinal and a drop of hydrochloric acid added

ARABAN AND XYLAN

The test was conducted as for lignin but the sections were warmed for ten minutes

PECTIN

The sections were stained in a dilute aqueous solution of ruthenium red

TANNINS

The sections were placed in 10% aqueous ferric chloride plus a little sodium carbonate

SAPONINS

The sections were placed in concentrated sulphuric acid

RESINS

The sections were left in a 7% aqueous solution of copper acetate for 5 days

OXIDASE

The sections were placed in a 1% solution of benzidine in 60% alcohol

PEROXIDASE

The sections were placed in a 1% solution of benzidine in 60% alcohol and a drop of hydrogen peroxide added

CATALASE

The sections were placed in a 1% solution of gum arabic and a drop of hydrogen peroxide was added

NITRATES

The sections were placed in a 0 1% solution of diphenylamine in 75% sulphuric acid

PHOSPHATES

The method used was that employed by Humphrey and Dufrenoy (29) The sections were placed in a mixture of 5 ml of a solution of 20 8 ml of sulphuric acid and 6 41 grms of ammonium molybdate made up to 250 ml with distilled water and 1 ml of a solution of 0 5 grms of 1-amino 2 naphthol 4 sulphonic acid and 5 75 grms of sodium bisulphite, plus 5 ml of a 20% solution of sodium sulphite made up to 90 ml with distilled water

CALCIUM

The sections were placed in a 2% aqueous solution of oxalic acid The acid was withdrawn after thirty minutes a coverslip added and alcohol allowed to diffuse under the coverslip

CALCIUM OXALATE

The sections were placed in a 7% aqueous solution of copper acetate

SULPHATES

The sections were placed in a 1% solution of benzidine chloride in 3% hydrochloric acid

Results—The parenchymatous tissues of healthy gladiolus corms contain starch grains, but they are not present in the tissue of the vascular bundles In corms in which the disease is active excessive accumulation of starch occurs in the infected tissue (Plate VII, figs. 23 and 24). The surrounding healthy cells do not show any marked reduction in the number of starch grains present. Hopkins (28) noted that starch accumulated in tulip bulb tissue infected with *Botrytis tulipae*.

Pectin is absent from the diseased areas but is present as the middle lamella in healthy tissue. The capacity of *Botrytis* species to utilize pectin has been noted by several workers. A report by the Food and Vegetables Committee, Department of Science and Industrial Research (9) states that in studies of the parasitism of *Botrytis* sp. on the apple it was found that the organism utilized considerable quantities of pectin. Davidson and Willaman (8) reported that *Botrytis cinerea* produces pectinase. The capacity of *Botrytis* to utilize pectin explains the rapid disorganization of infected tissue.

The cell walls are changed to a material which stains yellow with iodine and is apparently a dextrin.

No reducing sugars were detected in healthy tissue but glucose zones developed in some sections of diseased tissue which were tested. The ose zones did not appear till after forty-eight hours, which suggests the reducing sugar present was glucose.

Saponins and the enzymes catalase and peroxidase were present in both healthy and diseased tissue. Oxidase was not detected in diseased tissue and it was only detected in developing shoots of the healthy tissue.

Free nitrates, lignin, methyl pentoses, resins, tannins, calcium, calcium oxalate and sulphates were not detected in either healthy or diseased tissue. Suberin was not detected in or at the edge of active diseased lesions. The phosphate test was not conducted on material of this type. No deposits of protein material were detected in healthy or diseased tissue.

A pigment which changes to vinaceous rufous—Ridgeway's colour chart (46)—on the addition of alkali is produced in infected tissue. This pigment is water soluble and when extracted from the corm is amber yellow coloured. It changes to vinaceous rufous at pH 6.8 and may be precipitated from aqueous solution by the addition of excess acid. The chemical nature of this material has not been determined.

Small quantities of the same pigment are produced in gladiolus corms infected with *Septoria gladioli* or *Bacterium marginatum*.

The pigment is not produced by *Botrytis* when the organism grows on potato dextrose agar or gladiolus dextrose agar. *Botrytis* was grown on autoclaved gladiolus corms but no indicator pigment was produced Therefore the pigment is produced by living gladiolus corm tissue when invaded by *Botrytis*, *Septoria gladioli*, or *Bacterium marginatum*

Kreuzer (35) found that a pigment which changes in colour from red at pH 8 5 to yellow brown at pH 4 5 is produced in onion roots infected with *Phoma terrestris*

The chemistry of infected tissue in corms in which the disease has been arrested differs in several features from infected tissue of corms in which the disease is active The disorganized tissue contains little or no starch but is similar in other respects to that described previously

The phosphate test demonstrated the presence of free phosphate or loosely combined phosphorous compounds in the healthy tissue but no reaction for phosphates was obtained in diseased tissue Humphrey and Dufrenoy (29) found that free phosphate appears in oat tissue infected with crown rust Apparently in the case of *Botrytis* the phosphates are used by the fungus and do not accumulate This tissue is surrounded by a layer of cells about 1 to 2 millimetres wide which is practically devoid of cell contents The cell walls are not distorted in shape but stain yellow with iodine showing that they have been partially broken down to dextrins The middle lamella stains progressively fainter with ruthenium red towards the disorganized tissue indicating that it has been partly dissolved

This layer is surrounded by rectangular cells with suberinised walls and beyond the tissue is normal (Plate VII fig 25)

Pathogenicity and Host Range

The pathogenicity of *Botrytis* to gladioli was demonstrated by inoculating healthy corms with a pure culture of the organism The organism was introduced by needle puncture and the corms were then placed in jars containing a free water surface After several days brown lesions typical of the disease in the field developed (Plate V fig 12) and they increased rapidly in size with continued incubation

Isolates were made from the edges of lesions on artificially infected corms and *Botrytis* was consistently isolated

The disease has only been observed under field conditions on varieties of *Gladiolus primulinus* and gladiolus hybrids

Limited infection experiments using the technique described above were conducted on corms or bulbs of cyclamen narcissus *Gladiolus colvillii* and *Ixia grandiflora* Infection occurred in corms of *Gladiolus colvillii* and *Ixia grandiflora* though the disease has not been observed on these plants in nature

Method of Infection in the Field.

It has previously been stated that *Botrytis* enters the gladiolus corm along the vascular bundles Large numbers of infected corms were examined and in all cases at least portion of the core of the corm was infected and had spread from the core to other portions of the corm along the vascular bundles In no case had the fungus entered the corms through parenchymatous tissue

From theoretical considerations the fungus could enter the core of the corm through the old corm from infected soil, it could pass down into the corm from infected foliage or it could enter the corm by infection of the cut stem, or the old corm, after the corms were dug

In most of the infected corms examined the whole of the core was diseased In some corms however only the top portion of the core was infected In these cases infection could have occurred by the fungus passing down into the corms from infected leaves or by infection of the cut stem end while the corms were on the drying racks (Plate V fig 8) A few corms only showed infection of the lower portion of the core Infection could have occurred from infected soil or by infection of the corms on the drying racks

Pot experiments were conducted in 1941 42 in order to determine the probable method of infection in the field

The susceptible variety Picardy was used for the experiment and the plants were grown in virgin, red mountain soil in 8 in pots One series was planted into soil which was inoculated by mixing it with infected corm material The leaves of another series were inoculated, before the plants flowered, by brushing them with conidia developed on artificially infected flowers Another two series were inoculated in the same way immediately after flowering After inoculation the plants were held in a humidity chamber for twenty four hours and then removed to the glass-house

Abundant lesions, typical of *Botrytis* infection in the field developed on all the inoculated leaves

The corms were dug six weeks after flowering and the pre flowering inoculated series one of the post flowering inoculated series and the soil inoculated series were stored in closed tins to reduce the rate of drying of the corms The other post flowering inoculated series was stored under good conditions on a wire netting stretcher

The freshly cut stem ends of two other series were inoculated by brushing with dry conidia of *Botrytis* One series was stored in a closed tin and the other on a wire-netting stretcher

Two other series were not inoculated and one stored in a closed tin and the other on a wire netting stretcher

There were six replicates in each series throughout the whole experiment

After storage for eight weeks the corms were examined and it was found that typical *Botrytis* rot had developed in the series in which the cut ends of the corms were inoculated at digging time and then stored in closed tins The corms in all the other series did not develop the disease

This experiment demonstrated that infection can occur through the cut stem ends of the corms, if they are stored under humid conditions The experimental conditions may not have been favorable for soil infection as the pots were well drained and soil infection may require a high soil moisture content However evidence in the field does not suggest soil infection is important and serious infection of corms, which were grown on virgin soil has been observed The failure of soil sterilization experiments to control the disease supports this view

As heavy leaf infection was obtained in the experiment it is unlikely that infection of corms develops by the disease passing down from the leaves into the corms This view is supported by the failure of foliage sprays to control the disease and evidence from the control experiments conducted subsequent to this experiment suggests that all field infection occurs on the drying racks after digging

As some of the infection on the racks could occur through the cut stem end of the corm and some through the old corm it seemed possible that the amount of infection would be reduced if the tops were not removed from the corms after digging

Therefore an experiment was conducted in the 1943 44 season in which 200 corms of Picardy were dug and stored without removing the tops, on wire netting stretchers The tops were removed from an equal number of Picardy corms and they were stored under the same conditions

The corms were examined after ten weeks' storage and it was found that 45 per cent of the corms from which the tops had been removed were infected while only 34 per cent of the other series were infected Thus the disease enters both from the cut stem end and through the old corm

Control

Control measures recommended by Dodge and Laskaris (11) and Moore (37) are stringent field and storehouse sanitation These methods would probably reduce the disease but are not a completely satisfactory solution to the problem

The experiments on control described here were designed to prevent the entry of the fungus into the corms As the disease attacks the interior of the corm it is obvious that dipping infected corms with fungicidal solutions will not control the disease A limited number of experiments were carried out in an attempt to sterilize infected corms by volatile materials and these will be described later but the method was not successful

Because of the three possible methods of entry described in the preceding section experiments were conducted on soil sterilization spraying to prevent foliage infection and dipping of the corms at digging time

Experiments were also conducted on the influence of time of digging and to determine whether any varieties of the gladiolus were resistant to the disease

SOIL STERILIZATION EXPERIMENTS

An experiment on the effect of soil sterilization was conducted in the 1940 41 season

Method—Trenches 4 inches deep and 40 feet long were dug and the fungicidal materials were then applied The soil was then replaced and the treated areas covered with bags for five days After fourteen days 100 corms of the variety Picardy were planted in each treated row and in untreated row The experiment was laid out as a randomized block and there were four replicates of each treatment

The treatments tested were— formalin 2 per cent applied at the rate of ½ gallon per square yard bleaching powder at the rate of 1 lb per 20 square yards and carbon bisulphide at the rate of 1 pint per square yard

Six weeks after the plants had flowered they were dug and placed on wire netting stretches in the same order as their position in the field After storage for six weeks the scales were removed from the corms and the number infected with *Botrytis* were determined

Results—The plants grew normally except that the foliage of the carbon bisulphide treated rows was deeper coloured than the controls during the early stages of growth though the effect was not maintained throughout the season This was apparently due to partial soil sterilization (Waksman 55)

TABLE 6

—	Control	Formalin	Bleaching Powder	Carbon Bi-sulphide
Percentage	29 6%	30 9%	26 3%	25 2%
Angle	32 94°	33 77°	30 86°	30 07°

Determination of the F value (Snedecor, 50) showed that the differences in the experiment were not significant. The method of angular transformation is taken from Cochran's paper (6)

Soil sterilization does not therefore appear to offer any possibility of control, and this experiment, considered together with evidence previously presented, indicates that soil infection is not an important factor in the disease Therefore soil sterilization experiments were not conducted in subsequent seasons.

SPRAYING EXPERIMENTS.

Methods.—Corms of the variety Picardy were planted in rows of 100 corms according to ordinary commercial practices The experiments were sprayed in randomized blocks, each row of 100 corms constituting a single plot. There were four replicates of each treatment and the same number of unsprayed plots

The plots were dug six weeks after flowering and placed on wire-netting stretchers in the same order as the position of the plots in the field. The scales were removed from the corms after six weeks' storage and the number of infected corms determined

Results (1940-41 season)—Lime sulphur 1 in 40 and 6 4 40 Bordeaux mixture were tried in that season Agral II was added to the sprays at the rate of 1 in 2,000, and good wetting of the foliage was obtained. Spraying was commenced one week after flowering, as foliage infection does not occur before flowering under Kalorama conditions

Lime sulphur was ineffective and lesions developed on the sprayed plants. Bordeaux mixture prevented foliage infection for a fortnight after application, but later some lesions developed as the spray washed off the leaves

Table 7 shows the percentage of infected corms —

TABLF 7

—	Unsprayed	Bordeaux	Lime Sulphur
Percentage	23%	26·8%	24·5%
Angle	28·66°	31·15°	29·68°

The F value was determined and it was shown that the differences were not significant. However, it was felt that this could have been due to an insufficient number of applications of Bordeaux, and therefore a further spraying experiment was conducted in the 1941-42 season

In that season 6:4:40 Bordeaux mixture, plus 1 in 2,000 Agral II., was applied at weekly, fortnightly, and monthly intervals, copper oxychloride ("Soltosan") at the rate of 3 lb. in 40 gallons, plus 1 in 3,000 Agral II. at fortnightly intervals, and a commercial copper dust ("Coppodust") at fortnightly intervals, were tried.

The copper oxychloride caused slight foliage injury, and did not prevent leaf infection. Copper dust did not cause injury but was ineffective. Bordeaux was effective in reducing the number of leaf lesions in the plots that were sprayed at weekly and fortnightly intervals. It delayed infection in plots sprayed at monthly intervals but did not prevent its development before the corms were dug.

Table 8 shows the percentage of infected corms. Analysis by the F value showed that the differences were not significant:—

TABLE 8.

	Unsprayed	Bordeaux Weekly	Bordeaux Fortnightly	Bordeaux Monthly.	Soltosan	Coppodust.
Percentage	2·5%	3·4%	6·1%	4·0%	4·8%	4·4%
Angle	9·17°	10·83°	14·23°	11·46°	12·60°	12·07°

In this season the percentage of infected corms on the untreated plots was low, and the experiment was not therefore entirely conclusive However, no evidence of possible control by spraying was obtained for the second successive year, and therefore spraying experiments were not conducted in subsequent seasons.

TREATING THE CORMS AT DIGGING TIME.

Dipping of corms, bulbs and tubers is usually conducted during the dormant period before planting, with the object of destroying diseases present on the surface of the corm. However, this would not be effective against the *Botrytis* disease of the gladiolus and therefore experiments were conducted to find a method of preventing entry of the disease into the corms

L. Hawker (25) tried dipping narcissus corms in cold formalin at digging time but it did prevent infection with *Botrytis narcissicola* She found, however, that cold formalin, brassisan, folosan, and ceresan reduced losses due to *Fusarium bulbigenum*. F. Weiss *et al* (57) found that mercury compounds, particularly ethyl mercuric chloride and ethyl mercuric phosphate, were effective in preventing *Fusarium* basal rot of narcissus. A two-minute dip was as effective as longer treatments. The treatment was most effective if given immediately after digging. They found that the treatments caused injury to the flower buds in subsequent crops, and they did not achieve a practical compromise between effective control and no flower injury. A number of treatments at digging time have been tried against *Botrytis* of the gladiolus.

Methods.—After digging, the corms were washed free of soil with a water spray and then counted into batches of 100. They were then placed in light hessian bags and dipped in the fungicidal solutions. After draining they were then spread out on wire-netting stretchers and stored on racks for drying. There were four replicates of each treatment and they were arranged on the stretchers in a randomized block arrangement.

After storage for six weeks the scales were removed and the number of infected corms determined

Results (1940-41 season).—Dipping treatments tried were lime sulphur 1 in 20 for six hours and copper sulphate 2 per cent. for 24 hours Another series was dusted with penta-chloro-nitro-benzene ("Folosan") The variety Wolfgang von Goethe was used for the experiments Gram and Thomsen (20) found 2 per cent. copper sulphate effective in controlling *Botrytis tulipae*. Pentachloro-nitro-benzene was found by Smieton and Brown (49) to control *Botrytis cinerea* on lettuce

TABLE 9

—	Untreated	Lime Sulphur	P.c.n.b.	Copper Sulphate.
Percentage ..	4·5%	9·3%	2·0%	No count possible
Angle ..	12·27°	17·71°	8·00°	

The F value was determined and the differences found to be non significant.

Copper sulphate caused severe injury and no count of infected corms was possible.

Neither of the other treatments caused any significant reduction in the number of infected corms

Results (1941-42 season)—In that season shorter dipping times were employed to guard against similar injury to that produced by the copper sulphate treatment The variety Hindenburg's Memory was used for the experiment. 6:4:40 Bordeaux mixture, plus 1 in 2,000 Agral II., for half an hour; lime sulphur, 1 in 40, plus 1 in 2,000 Agral II., for half an hour; mercuric chloride (corrosive sublimate), 1 in 1,000 for 1 hour, and a commercial brand of copper dust "Coppodust" were tested

Table 10 shows the number of infected corms —

TABLE 10

	Untreated	Corrosive Sublimate	Bordeaux	Cu Dust	Lime Sulphur
Percentage	5 9%	0 0%	3 4%	3 2%	1[illegible] 4
Angle	14 0[illegible]	1 43	10 70	10 24°	[illegible]0 66

Whole experiment highly significant by F test

Difference for significance at 1 per cent level 3 48°
Difference for significance at 5 per cent level 2 48°

The method of analysis of variance described by Snedecor (51) was used

Both corrosive sublimate and copper dust produced a reduction in infected corms which was significant at the 1 per cent level though the control exercised by copper dust was not sufficient to be of much commercial value Corrosive sublimate exercised good control but caused a superficial injury in the form of a hard brown depression along the base of the scales on the corms However when these corms were grown the plants were normal and produced normal flowers Bordeaux mixture caused a reduction in the number of infected corms which was significant at the 5 per cent level but it was not sufficient to be of commercial value

The number of infected corms produced in the lime sulphur treated corms was significantly higher than the untreated This was apparently due to the fact that the treatment delayed the drying of the corms and they remained susceptible for a longer period than untreated corms

Results (1942 43 season) —In this season corrosive sublimate 1 in 1 000 plus Agral II 1 in 2 000 for one minute and for 30 minutes and Hortosan D P at the rate of 1 oz in 5 gallons for two minutes and fifteen minutes were tested The corms were placed in bags of cheese cloth instead of hessian bags The variety Picardy was used for the experiment

Hortosan D P is a proprietary material containing 2 5 per cent of mercury as an organic mercuric compound

TABLE 11

	Untreated	Corrosive Sublimate 1 minute	Corrosive Sublimate 30 minutes	Hortosan 2 minutes	Hortosan 15 minutes
Percentage	46 7	4 1%	4 8%	0 0	0 [illegible]
Angle	43 13°	11 64	1[illegible] 64	14 1[illegible]	1 41

The whole experiment was shown to be highly significant by the F test

Difference for significance at 1 per cent level 5 85
Difference for significance at 5 per cent level 4 07°

All treatments caused a significant reduction in the number of infected corms. Hortosan D.P. for fifteen minutes was significantly better than all other treatments. There was no significant difference between the two corrosive sublimate treatments. No injury was caused by any of the treatments

Results (1943-44 season).—The primary object of the experiment in this season was to test the effectiveness of other proprietary organic mercurials, and to repeat tests on Hortosan D.P. for fifteen minutes and corrosive sublimate, plus 1 in 2,000 Agral II., for two minutes. Aretan (containing 3·5 per cent. mercury as methyl-oxy-ethyl-mercuric chloride used at the rate of 4 oz. in 10 gallons) and Zetan (synonymous with New Improved Semesan Bel, containing 12 per cent. hydroxy mercuric nitro phenol and used at the rate of 1 lb to 10 gallons), were also tested. A dipping time of fifteen minutes was used for both materials.

The variety Picardy was used for the experiments and the corms were dipped in light hessian bags

TABLE 12

	Untreated	"Hortosan" D P	'Zetan'	'Aretan'	Corrosive Sublimate
Percentage	47·5%	9·4%	10·5%	16·9%	13·6%
Angle	43·55°	16·84	18·80°	24·27°	21·21°

Whole experiment hightly significant at 1 per cent. level

Difference for significance at 1 per cent level 8·31°

Difference for significance at 5 per cent. level . 5·93°

All treatments caused a significant reduction in the number of infected corms There was no significant difference between treatments at the 1 per cent. level, but at the 5 per cent. level Hortosan D P. was significantly better than Aretan or Corrosive sublimate.

REPLENISHMENT OF SOLUTION.

From an economic point of view it would be desirable to be able to use the same solution for several batches of corms It is obvious that some reduction in strength of the dipping solution will occur after each batch of corms. Gilmore and Robinson (18, 19) investigated the loss in strength of corrosive sublimate solutions after dipping seed potatoes

Therefore in 1944 a dipping experiment was conducted to determine the loss in strength of Hortosan D.P

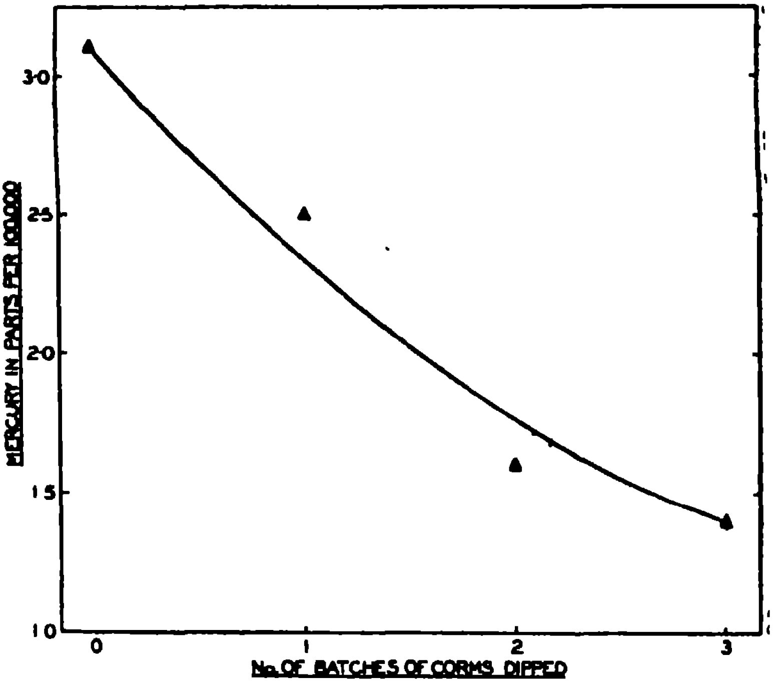
Method.—Four gallons of Hortosan D.P. solution was prepared and a sample of the solution taken. Then three successive batches of 200 washed corms were dipped in light hessian bags. Each dipping was for exactly fifteen minutes. After each dipping, samples of the solution were taken. The mercury content of the solutions was determined by Mr. W. Jewell, Agricultural Research Chemist of the Victorian Department of Agriculture.

Results.—The results are shown in Table 13 and are presented graphically in Text fig. 3.—

TABLE 13.

	Original	After One Batch of Corms.	After Two Batches of Corms	After Three Batches of Corms.
Mercury in parts per 100,000	3·1	2·5	1·6	1·4

EFFECT OF DIPPING SUCCESSIVE BATCHES OF CORMS IN HORTOSAN D. P



In the figure a curve has been fitted to the points. It is not surprising that the points do not fall exactly on the curve, since variability would be expected because of variation in the size of the corms and the amount of soil on the corms.

Gilmore and Robinson (18) have pointed out a similar variability when dipping potato tubers in corrosive sublimate. Because of this factor they developed a field method (19) for determining the amount of corrosive sublimate necessary to replenish the solution.

Unfortunately, no similar method could be developed for organic mercurials, as the analysis of these materials is essentially a laboratory determination.

It is realized that any general recommendations cannot be accurate, but if the dip is not used for more than three or four batches of corms the error would not be of great practical importance. A calculation based on the graph of the results was made, and it was found that ½ oz. of Hortosan D.P. should be added after dipping each batch of 500 corms in 10 gallons of a solution of 2 oz. of Hortosan D.P. per 10 gallons for fifteen minutes.

EXPOSURE OF CORMS TO VOLATILE FUNGICIDES.

The first use of a volatile material against a fungal disease was in the control of Blue Mould (*Peronospora tabaci*) of tobacco (Angell *et al* (1)). Subsequently, other related compounds have been used (59).

Various volatile materials were tested against the *Botrytis* of gladiolus. In preliminary tests the materials were tested against the fungus itself, using a slight modification of the method described by Oserkowsky (42). The effect of promising materials on healthy corms was then determined.

Methods.—Potato dextrose agar was poured into sterile 4-in. petri dishes. Before the medium had set a sterile 1-in. petri dish lid was placed in the centre of the medium. The plates were then inoculated with *Botrytis* and incubated for five days. One ml. of the volatile material was then pipetted into the small petri dish The cultures were examined after 24, 48, and 72 hours and a small portion of the mycelium transferred to a potato dextrose agar slope The slopes were then incubated and examined for growth

Results—The results are shown in Table 14:—

TABLE 14

Chemical.	Results,		
	24 Hours	48 Hours	72 Hours
Benzol	+ +	+ +	+ +
Toluene	+ +	+ +	+ -
Dioxan	–	–	
Paradichlorbenzene	– –	– –	+

+ + Colony flattened No growth from subculture
+ – Colony flattened Growth from subculture
– – Colony unaffected Growth from subculture

Benzol and toluene were therefore effective in killing the fungus after exposure for 24 hours Dioxan and paradichlorbenzene did not have any visible effect after exposure for 48 hours After exposure for 72 hours both materials caused flattening of the colonies but did not cause death of the fungus

To determine the effect of exposure of gladiolus corms to benzol vapour six corms of the variety, Mrs S A Errey, were enclosed in a closed tin with a layer of benzol at the bottom, for 24 hours The corms were then planted

The plants produced showed distortion, and the flowers which developed were severely distorted On digging the plants, it was found that the corms produced were abnormal in shape (Plate V, fig 10)

This method of treatment did not show promise of success and experiments of this type were not continued

TIME OF DIGGING

Species of *Botrytis* have been frequently shown to be favored by cool humid conditions (2 25) It was therefore anticipated that if corms were dug before the weather became cool and humid they would possibly escape the disease

Miss Hawker found that narcissus bulbs showed heavier losses due to *Botrytis narcissicola* at low or moderate rather than higher temperatures

Methods Corms of the variety Picardy were planted in rows containing 100 corms Four rows were planted at each of three periods separated by a month They were dug six weeks after flowering

The corms were then placed on wire netting stretchers After storage for six weeks the scales were removed from the corms and the number of infected corms determined

Results The corms were dug on the 2nd April 23rd April, and on the 7th May The number of infected corms is shown in Table 15

TABLE 15

	Time of Digging		
	Early	Midseason	Late
Percentage	0	[illegible]	21 7°
Angle	4 05	11 35	[illegible]

Whole experiment highly significant by F test

Difference for significance at 1 per cent level 6 77°

Difference for significance at 5 per cent level 5 15°

Therefore by digging the corms early the disease was almost entirely avoided Unfortunately only rainfall data are available for the Kalorama district and no data on humidity or temperature was obtained A study of rainfall data for Kalorama in 1941 showed that some rain fell on each of the four days after digging the early plants, but then no further rain fell for ten days Apparently these good drying conditions were unfavorable for the disease

A study of rainfall data for Kalorama in the succeeding four seasons showed that if corms are dug before the second week of March the rainfall is unlikely to be heavy following digging and therefore there is little chance of infection All corms dug later should be dipped

These observations were confined to the Kalorama district and no general recommendations are possible

VARIETAL RESISTANCE

Answers to inquiries made among growers suggested that certain varieties were resistant to the disease Therefore an experiment was conducted in the 1940 41 season to determine the relative susceptibility of various varieties to the disease

Methods The corms were planted in rows each containing 100 corms There were four replicates of each variety and the plot was laid down as a randomized block The corms were dug six weeks after flowering and placed on wire netting stretchers in the same relative position as the plots in the field After storage for six weeks the scales were removed and the percentage of infected corms determined

Results The results are shown in Table 16

TABLE 16

—	Variety [illegible]						
	Golden Goldens	Pelegrina	Wolfgang v Goethe	Miss New Zealand	Gate of Heaven	Pearly	Red Lory
[illegible]	1 [illegible]	[illegible]	1 [illegible]	[illegible]	18 9%	[illegible]%	4 4%
Angle	[illegible] 04	01	[illegible]	0	[illegible]5 70	31 31	1[illegible] 18

Whole experiment highly significant by F test

Difference for significance at 1 per cent level 3 53°
Difference for significance at 5 per cent level 2 58°

Pelegrina Miss New Zealand and Red Lory all showed resistance to the disease but Miss New Zealand was significantly more resistant than the other varieties and Pelegrina was significantly more resistant than Red Lory

It is interesting to note that the foliage of Pelegrina was severely infected with the fungus and had almost completely died down before digging On the other hand Picardy showed some leaf spotting, but less than any other variety tested

According to growers reports, King Lear, Elinora, Mrs S A Errey, Black Opal, Champlain, Don Bradman, and Rose Dawn are also resistant to the disease

Discussion.

Botrytis corm rot is a disease which is favored by cool humid conditions Growers can therefore avoid infection of the corms by planting early so that the corms are dug in the early autumn However as most growers desire to produce flowers for the cut flower trade in addition to corms, they prefer to plant portion of their stock at intervals throughout the season so that all their flowers are not produced at the one time Therefore they must have recourse to the other control measures described Apart from the hope that in the future a large number of resistant varieties may be produced the knowledge that certain popular varieties at present grown are resistant will enable the grower to avoid the expense of unnecessarily dipping these varieties

The results obtained with various dips applied at dipping time show that very good control may be obtained with Hortosan D P Slightly less effective control can be obtained with corrosive sublimate plus Agral II and with Arctan Zetan also gives good control The higher degree of control obtained with Hortosan D P in the 1942-43 season than in the 1943 44 season may be due to the fact that the corms were dipped in muslin bags in the earlier season and in hessian bags in the latter Growers should preferably use muslin bags It must be stressed that the corms be well washed before dipping as many organic mercurials are inactivated by soil Dipping must be carried out as soon as possible after digging The suggestion for replenishing the Hortosan dip is tentative and growers should not use the replenished dip for more than three or four batches of corms

Observations suggest that the main method of overwintering of the disease is on infected corms These usually bear abundant sclerotes and as has been shown these germinate under certain conditions to produce conidia The conidia produced from this source would then infect flowers left in the field and as abundant conidia are rapidly produced on flowers a heavy spore load would be rapidly built up Growers should therefore destroy infected corms by deep burial or by burning They should not leave unwanted flowers in the field but should cut them and destroy them by burning or burial

Good storage conditions are important and the maximum of ventilation should be provided This is best achieved by using wire netting stretchers arranged on racks However it is felt that good storage conditions and attention to sanitation as recommended in the preceding paragraph will not eliminate the necessity for dipping but rather all these measures are complimentary

Acknowledgments.

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Mr W Jewell of the Victorian Department of Agriculture conducted the analysis of mercury dipping solutions and Dr H C Forster of the same Department prepared the statistical analysis on the relation between vitamins and increasing dextrose content on the growth of the fungus This work was conducted at the Biological Branch Department of Agriculture Victoria

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Explanation of Plates

PLATE V

Fig. 1.—Slightly infected corm.

Fig. 2.—Mummified corm. Note the sclerotes.

Fig. 3.—Infected corm showing many [illegible] sclerotes of Botrytis.

Figs. 4–7.—Sections of corms showing progressive stages of infection.

Fig. 8.—Section of a corm showing infection commencing at the top of the core.

Fig. 9.—[illegible] of Botrytis × [illegible]

Fig. 10.—Corm showing the effect of [illegible] the growth of the corm [illegible] the subsequent crop.

Fig. 11.—The development [illegible] sclerote × 10.

Fig. 12.—A [illegible] infection of a corm with Botrytis.

PLATE VI

Fig. 13.—[illegible] infection with Botrytis.

Fig. 14.—[illegible] but the plant was sprayed with Bordeaux mixture at flowering time.

Fig. 15.—Collar [illegible] Botrytis. Note the sclerotes on the [illegible] region of the plant.

Figs. 16–18.—Progressive stages of infection of flowers with Botrytis. Note the conidia in Fig. 18.

Fig. 19–22.—The effect of light [illegible] Botrytis [illegible] in 19 [illegible] were held at 3 [illegible] 9 was exposed to light [illegible] 0 kept away from light. Those [illegible] and 22 were held [illegible] exposed to light [illegible] kept away from light.

PLATE VII

Fig. 23.—Section showing [illegible] between healthy and diseased tissue. Note the [illegible] of [illegible] and the sharp line of demarkation between the healthy and diseased tissue. Stained with [illegible] × 35.

Fig. 24.—Section showing [illegible] yellow [illegible] between the healthy and diseased tissue. Note the [illegible] the diseased [illegible] low light. Stained with [illegible] light green × 35.

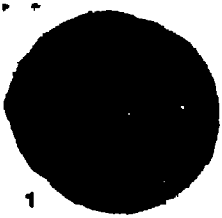
Fig. 25.—Freehand section through an infected lesion. Note [illegible] between the starch-free [illegible] and the [illegible] tissue. Stained with iodine and Sudan III × 42.

Fig. 26A.—Longitudinal section through an infected vascular bundle × 35.

Fig. 26B.—Enlargement of portion of 26A showing apparently unaffected xylem [illegible] and almost completely disorganized phloem tissue. Stained with Heidenhain's Haematoxylin and light green × 85.

Fig. 27.—Transverse section through [illegible] infected vascular bundle. Note the disorganization of infected tissue and the sharp line of demarkation between healthy and diseased tissue. Stained with Heidenhain's Haematoxylin and light green × 35.

Fig. 28.—Tangential section through an infected vascular bundle. Note the heavy fungal infection of the vascular bundle and the absence of hyphae in the adjacent parenchymatous tissue. Stained with Heidenhain's Haematoxylin and light green × 35.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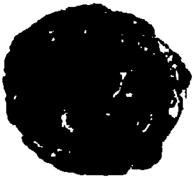
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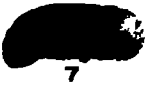
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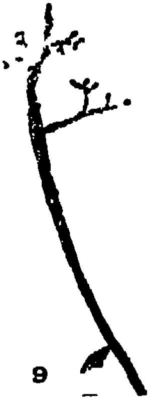
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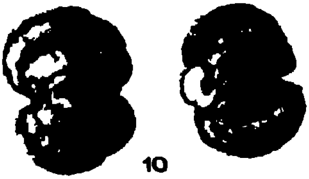
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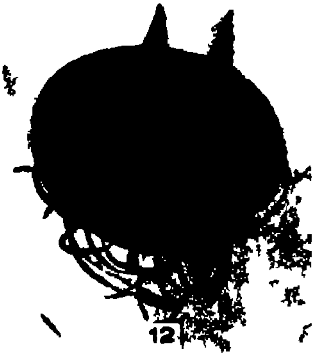
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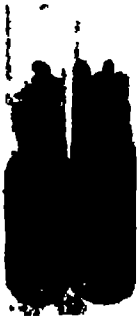
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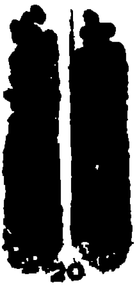
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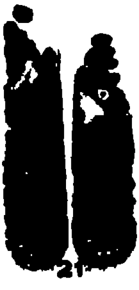
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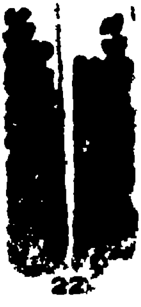
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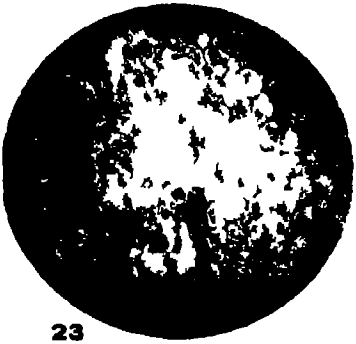
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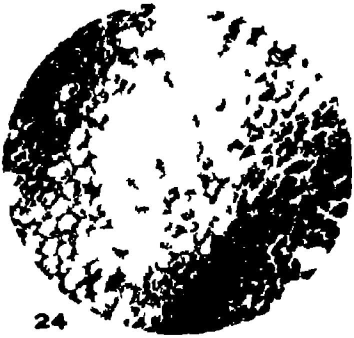
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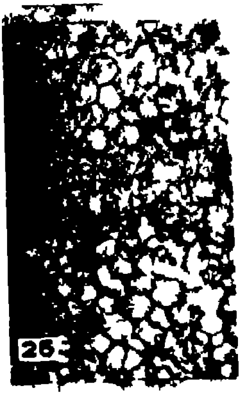
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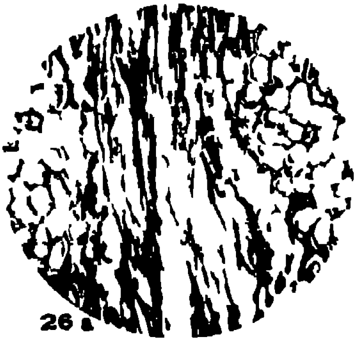
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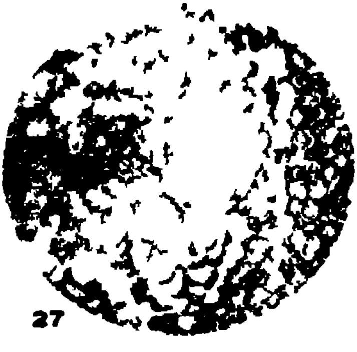
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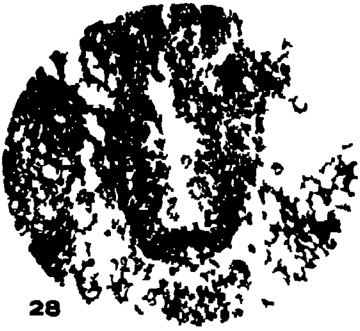
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[Proc. Roy. Soc. Victoria, 57 (N.S.), Pts. I.-II., 1945.]

Art VI.—*Chonetidae from the Palaeozoic Rocks of Victoria and their Stratigraphical Significance.*

By EDMUND D. GILL, B.A., B.D.

[Read 14th December, 1944; issued separately 10th December, 1945.]

Summary.

A survey is made of all the known Chonetidae from the Palaeozoic rocks of Victoria. Comments are made on species of *Chonetes* and *Anoplia* already described, and the following new species are erected—*Chonetes bowieae C. productoida, C. killarensis, C psiloplia, C ruddockensis, C. taggertyensis, and C. gaskini.* The affinities of these forms with those found elsewhere are given, and their stratigraphical significance commented upon. A subdivision of the Yeringian Series is proposed.

Introduction.

Fossils of the brachiopod family Chonetidae (the classification of the *Fossilium Catalogus* is adopted) are known in Victoria only from Silurian and Devonian rocks, and they belong to the two genera *Chonetes* (*sensu stricto*) and *Anoplia.* The following table summarizes our knowledge of the occurrence of this group:—

Series.	Age.	Genus and Species.
Buchan Beds .	Middle Devonian .	*Chonetes australis* McCoy
Bindi Beds	Middle Devonian	*C australis* McCoy *C gaskini*, sp nov.
Yeringian	Lower Devonian (in part at least)	*C bowieae* sp nov. *C cresswelli* Chapman *C killarensis*, sp. nov. *C. productoida*, sp nov. *C psiloplia* sp nov *C robusta* Chapman *C ruddockensis*, sp. nov *C. taggertyensis*, sp nov *Anoplia australis* Gill *A withersi* Gill
Melbournian ..	Lower Ludlow (in part at least)	*Chonetes melbournensis* Chapman

The Devonian genera *Eodevonaria* and *Chonostrophia* have not been found in Victoria. Fig. 1 attempts to represent diagrammatically the relationships of the various genera of the family Chonetidae, and of that family to the closely-related family Productidae.

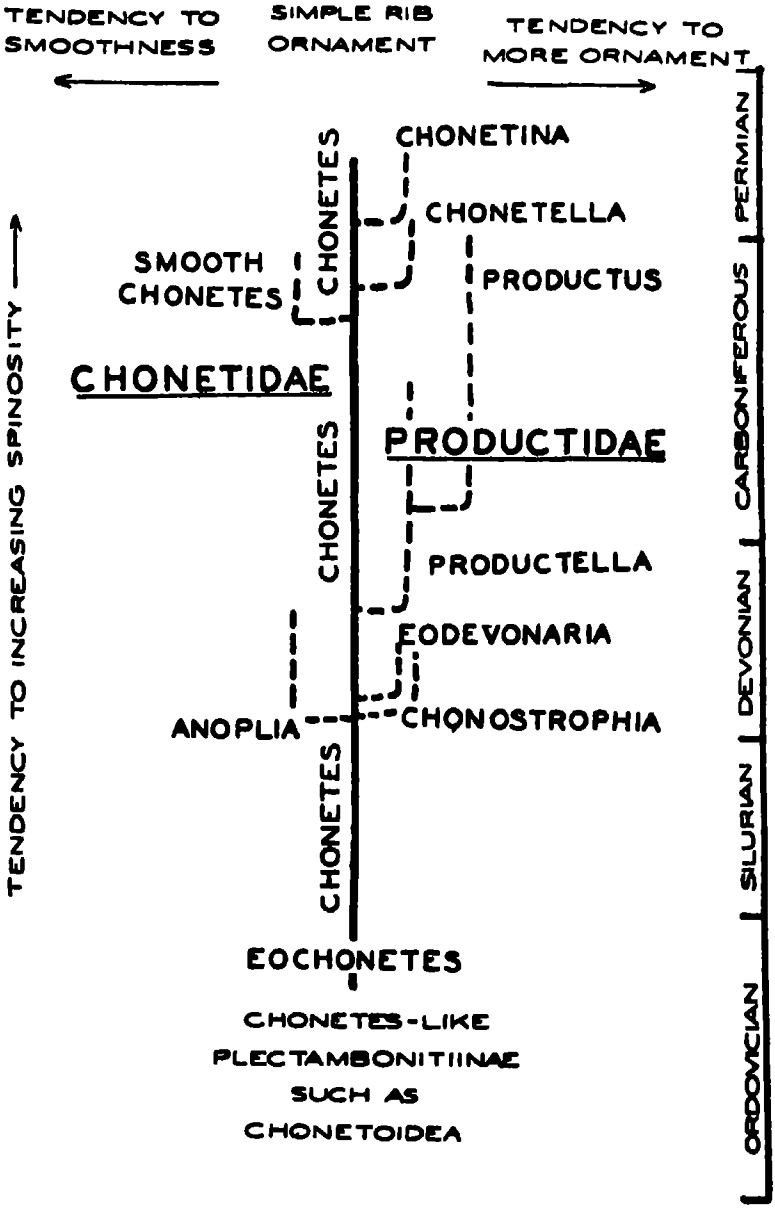

FIG. 1.—Generalised diagrammatic representation of the evolutionary relationships of genera of the Chonetidae and Productidae. The remarkable persistence of *Chonetes* as a genus should be noted.

Discussion of the Genus Chonetes.

Class BRACHIOPODA Dumeril.

Family CHONETIDAE Hall and Clarke, 1895.

Genus **Chonetes** Fischer de Waldheim, 1837.

GENOLECTOTYPE *Chonetes* sp. Fischer = *C. variolata* D'Orbigny, 1842, as interpreted by De Koninck, 1847 (quoted from *Fossilium Catalogus*).

ETYMOLOGY OF GENERIC NAME.—The name of the genus is derived from the feminine Greek noun "chone," a funnel, but the form "chonetes" is masculine, and so strictly speaking all the trivial names should be masculine in agreement. Such they were made by many early writers, but feminine forms have been established by consistent recent usage, and it would be confusing now to change all the names.

DIAGNOSIS OF THE GENUS.

Inequivalve, equilateral chonetids, with a straight hinge-line, and a row of hollow spines along the ventral cardinal margin. Ventral valve convex; dorsal valve flat to concave. Interior ventral valve with two small teeth, unsupported by dental lamellae. Cardinal area narrow and smooth. Pedicle obsolescent as shown by closure of pedicle opening by a pseudo-deltidium. Muscle impressions non-dendritic. Surface usually covered with radiating striae or ribs; rarely smooth. Interior of shells commonly papillose in the pallial region.

PHYLOGENETICS.

The genus *Chonetes* is a simple expression of the forms previously grouped in the large family Productidae. It is the stock from which the Upper Palaeozoic productids were evolved. *Chonetes* appeared in the late Ordovician whereas *Productella* did not appear till the Devonian. The genera *Chonetes, Productella,* and *Productus* are very similar, differing characteristically in their degree of spinosity. The spines were probably a means of attachment compensating for a deficient or obsolescent pedicle (Beecher, 1898, p. 351). They may be regarded as a mark of group gerontism. In his diagnosis of the genus *Chonetes,* Schuchert writes of the spines (1913, p. 389), "These are prolongations of tubes which penetrate obliquely the substance of the shell along the hinge-line." Practically all the Victorian species have their spines at right angles to the hinge-line, and in a number of cases it is known definitely that the tubes penetrated the shell substance at right angles and not obliquely. A number of species have been noted both in European (e.g., *C. margaritacea*) and American (e.g., *C. setigera*) deposits which have their spines set at right angles to the hinge-line.

One visualizes the Chonetidae arising from Strophomenids of the type of *Chonetoidea* and *Sowerbyella,* which are quite chonetoid in structure but lack spines *Eochonetes* (Reed, 1917) is a plectambonitin with spines Breger (1906) erected the subgenus *Eodevonaria* to accommodate the denticulate forms of *Chonetes* Denticulation is so important a feature phylogenetically that Schuchert and Le Vene (1929) justifiably accorded *Eodevonaria* generic status

Spines are the principal generic feature of *Chonetes* and are also of considerable value for specific determination Hall (1892) writes, " Their comparative strength or direction often furnishes means for specific determination but I have not been able to satisfy myself that the number of spines on the hinge-line is of specific importance " The investigation of the Victorian forms suggests that the number of spines is constant in a species As Hall says, the nature of the spines is of specific importance For instance *C robusta* and *C killarensis* have a somewhat similar outline and ornament and both possess a median sulcus but the spines of each species are very different In *C robusta* they are long, thick, and straight whereas in *C killarensis* they are short, thin and sinuous Evidently there was rapid variation in this specialization of the genus

CLASSIFICATION

De Koninck (1847) classified *Chonetes* in his monograph according to the surface ornament, as follows —

A surface ornee de plis concentriques	1 Concentricae
plus de 100 cotes lisses	2 Comatae
moins de 100 mais plus de 30 cotes lisses	3 Striatae
de moins de 30 cotes lisses	4 Plicosae
de cotes rugueuses	5 Rugosae

In the light of later studies such a classification appears rather arbitrary and not based on genetic relationships, but Paeckelmann (1930) has created sub genera based on these divisions All the Victorian forms come within the class Striatae of De Koninck, i e, the *Chonetes sensu stricto* of Paeckelmann

Grabau and Shimer (1909) have classified *Chonetes* according to the presence or absence of ornament, and the presence or absence of a sulcus, as follows —

A *Chonetes* with radiating striae
  (*a*) Ventral valve with a median sulcus
  (*b*) Ventral valve without a median sulcus
B Smooth *Chonetes*

Group A is further sub divided by Grabau and Shimer according to the number of spines carried on the ventral cardinal margin All the species described in this paper come within Group A *C cresswelli*, *C robusta*, and *C killarensis* come within the sub-section " a," and the rest of the species in sub-section " b "

Prendergast (1944) has recently dismissed Schuchert's 1913 classification of productids based on means of attachment as "purely arbitrary," arguing that it "makes no allowance for a similarity of external form due to growth under similar environmental conditions" (p 10) This view is expressed more specifically in the statement that "Given the condition necessary for spine development, that is, a plentiful supply of $CaCO_3$, any species will probably develop spines in the same position in all its members The inclination of the spines to the body surface will depend upon the hardness of the sea-floor, arising at a high angle where the substratum is soft and being adherent where it is hard In modern lamellibranchs the temperature of the water has a marked effect on the thickness of the shell, the Arctic forms having a thick shell and the warm water forms of the same species a shell thin almost to fragility The difference between the Irwin forms, thin with short spines of small bore and those from Mt Marmion thick shelled with heavy spines of *Taeniothaerus subquadratus* (Morris) is possibly due to the difference in temperature of the sea at the two localities"

From a consideration of Prendergast's statements the following points emerge —

(1) Schuchert's 1913 classification is challenged but no mention made of his 1929 revised classification in the *Fossilium Catalogus*

(2) Phenotypes result from interaction between genetic constitution and environment Imagine, for instance a *Chonetes* individual with genes for spines of a certain size and shape orientated to the shell in a certain way That such genes existed may be justly inferred from the fact that spines of a certain character are always found on individuals of the same species If the optimum amount of calcium salts (or the ability to assimilate them) for building such spines in such a way is not present, then spines will develop but not of the strength that would otherwise be attained The whole exoskeleton will show signs of calcium starvation Paucity or plenty of calcium salts will not determine the absence or the presence of spines but their degree of development If calcium salts were absent altogether, there would be no exoskeleton and no shellfish If the calcium supply is low, then the whole exoskeleton will suffer by the shell being thin and the spines weak This is where Prendergast's argument breaks down However abnormal the conditions be, the means of attachment of the shell, viz, the spines, will be present, and so available as an objective means for the classification of species, genera, &c

(3) The means of attachment represent a line of rapid evolution for the group under discussion *A priori* such lines of rapid evolution should constitute good bases for classification The wide variety in the nature of the spines in the numerous

species of *Chonetes* indicates that there must have been a high mutation rate operating The spines on the exoskeletons of some modern shells seem to have no biological significance They may be mutations which remain because they are neither an advantage nor a disadvantage to the animal However the spines of the *Chonetes Productus* series appear to have played an important part by keeping the animal above the muddy sea floor where the water would be clearer and the supply of food more certain The group was a very successful one maintaining itself over a vast stretch of time and existing in prolific numbers The spinosity of these forms was apparently an important biological feature The series ended up with the Richthofeniidae which lost the power to elevate themselves by spines and elevated themselves above the sea floor by thickening the ventral valve until they looked like cyathophylloid corals

(4) Prendergast s reference to forms lacking calcium because in warm tropical seas is not easy to follow Coral reefs are tremendous accretions of calcium and such shells as the big clams indicate the withdrawal from tropical and sub tropical seas of very large amounts of lime The biggest and most extravagantly ornamented shells come from tropical seas Many extensive beds of limestone have been laid down in tropical waters These facts do not suggest paucity of calcium in tropical waters or lack of ability on the part of marine organisms in those areas to assimilate calcium

(5) Schuchert s 1929 classification separates off the Chonetidae as a distinct family from the Productidae The difficulty in taxonomy is that no systematic classification fits perfectly the complex variations of nature itself The systematist s task is to devise a classification which represents as closely as possible the known facts The early chonetids are closely allied to the Plectambonitinae being distinguished from them chiefly by the presence of cardinal spines Similarly the later chonetids are very closely allied to the productids which are distinguished by their increased spinosity and dendritic muscle impressions The productids constitute a clearly defined group of an increasing number of genera very widely distributed and most prolific They produced the most numerous the most varied the most widespread and the largest brachiopods in the late Palaeozoic' (Raymond 1939) The chonetids likewise form a biologically distinct numerically large and racially prolific group surviving in strength through the major part of the Palaeozoic (*vide* fig 1), and still maintaining its strength after giving rise to the productids In my opinion furthermore the early chonetids are quite as closely allied to the Strophomenidae as the later chonetids are to the Productidae and therefore there are as adequate grounds for separating the chonetids from the productids as there are for separating the chonetids from the strophomenids I

therefore agree with Schuchert's suggestion that they be represented as two separate families—the Chonetidae and the Productidae.

ADAPTATIONS.

Most of the species of *Chonetes* from Victoria are fairly thin-shelled forms, and usually there is a direct correlation between the weight of the shell and the strength of the spines. For example, *C. melbournensis* is a light form with fine spines, whereas *C. robusta* has heavier valves and stronger spines. The mechanics of these shells are very interesting. The spines are hollow, which affords strength with the lightness needed for a semi-floating organism; likewise corrugations of the shell give strength with lightness. The shells are usually flattish or concave, and so adapted to the semi-floating (i.e., not rigidly fixed) condition of an organism attached to a sub-stratum. The small space between the two valves indicates that the animal was slender, and so again adapted by its lightness to the particular place this genus had in the marine ecology of Palaeozoic times.

SOME CHARACTERISTICS OF THE VICTORIAN FORMS.

Reference has already been made to the setting of the spines on our forms at right angles to the hinge-line. *Chonetes maoria* Allan from the Reefton (Lower Devonian) Beds of New Zealand also has its spines inserted at right angles as is to be seen on a specimen in the National Museum, Melbourne.

Three species described in this paper (*C. robusta, C. cresswelli,* and *C. killarensis*) have a well-defined mesial sulcus in the ventral valve. The biological advantage of this would be the increased area for muscle attachment; perhaps also the sulcus would have a similar action to a keel and help to keep the animal floating evenly. The same feature has been noted in *C. variolata, C. verneuiliana, C. mesoloba, C. coronata, C. lepida, C. arcuata, C. mansuyi,* and *C. ningpoensis*. Reed (1921) describes this feature in a variety of *C. sarcinulata*. In the Victorian forms the sinus is a constant character of the species named, whereas it is claimed to be present in *C. acutiradiata* only sometimes, and it is not found in all the specimens named *C. maoria*. A mesial sinus is common in the Productidae.

Another feature of interest is the differentiated margin, such as found in *C. taggertyensis,* a similar phenomenon to which has been described in *C. sarcinulata, C. maoria, C. coronata,* and *C. syrtalis*. The structure is interesting phylogenetically in view of various modifications of the margin of the shell found in other Strophomenaceae, such as the deflected margin in *Leptaena* and *Strophonella,* variation in papillosity around the margin of the interior surface in *Chonetes,* variation in the external ornament around the margin of some species of *Productus,* and so on.

Notes on Species Previously Described.

CHONETES (CHONETES) MELBOURNENSIS Chapman

Chonetes melbournensis Chapman, 1903 pp 74 76, pl XI, figs 2-4

TYPE MATERIAL —Two syntypes National Museum, Reg No 636, is the internal cast of a ventral valve in micaceous bluish-grey, very fine-grained sandstone from " South Yarra Improvement Works " N M , Reg No 1419, is the internal cast of a dorsal valve in hard, greyish-brown, very fine-grained sandstone from " Sewerage tunnel near old Fishmarket "

DESCRIPTION OF VENTRAL VALVE (No 636) —This is a decorticated shell, small, slightly convex, flat on cardinal margins, measuring 5 mm long and 8 5 mm wide The profile rises about 75 mm above the plane joining the anterior and posterior margins Surface with about 80 fine radiating striae with some six more or less evenly-spaced, slightly stronger radii The preservation does not allow of detailed examination of the fine striae, but where clearly discernible, increase is by bifurcation Cardinal area narrow cardinal angles a little more than right angles Beak distinct, but not large, projecting just beyond the hinge-line Elongate papillae present, orientated to the striae (Not realizing that he was dealing with a decorticated specimen, Chapman described these impressions of papillae as pittings in the outer surface of the shell) Muscle scars indistinguishable No spines preserved

DESCRIPTION OF DORSAL VALVE (No 1419) —Small shell, very slightly concave, measuring 3 5 mm long, and 6 5 mm wide Surface covered with numerous poorly preserved fine radiating striae, some few being a little more pronounced than the rest, a clearly defined linear depression runs down the whole length of the centre of the shell Five long, very fine spines preserved from the ventral valve (two on one side of the umbo and three on the other), the longest being 2 5 mm

COMMENT —Examination of specimens other than the syntypes shows that *C melbournensis* carries ten long, pointed spines, five on each side of the umbo the spines are set at right angles to the hinge-line or curved outwards slightly Examination of a number of specimens also shows that the interiors of both valves are covered with fine papillae which are elongate, set in the inter-striate spaces, and orientated to the direction of the striae The external ornament appears also on the interiors of the valves, but less distinctly, and is absent where the muscle scars are well developed

In *C melbournensis* there is a stronger rib down the middle of the ventral valve and a corresponding linear depression on the dorsal valve This bipartition may be compared with the mesial sinus found in a number of species of *Chonetes* (*vide* p 131) Similar bipartition has been described in *C novascotica* (McLearn 1924) and *C aroostookensis* (Clarke 1907)

C melbournensis is a valuable index fossil but some care is necessary to ensure that specimens really do belong to this species The author has noted a variety of forms which have been referred in collections to this species but which do not conform to the type Extensive collecting and intensive study will have to be undertaken to separate out these various forms and accord them their proper status Sherrard and Keble (1937) recorded *C melbournensis* from New South Wales Mrs Sherrard kindly allowed me to examine these specimens However, they are possibly small stropheodontids and certainly not *Chonetes* Many stropheodontids simulate *Chonetes* e g *Stropheodonta bipartita* (Chapman) from the Yeringian rocks of Victoria Thomas (1937) has used *C melbournensis* as a zone fossil in the series of sediments at Heathcote but this form is not *Chonetes* either if the specimens collected by Professor Hills from this horizon are the form to which Thomas refers Like the New South Wales fossil it is devoid of spines and only simulates *Chonetes* in its general form and ornament The record of *C melbournensis* from Auburn and Balwyn near Templestowe (Chapman 1914 p 215) is also incorrect

Affinities—*C melbournensis* is comparable with *C novascotica* of the North American succession and *C striatella* of the European succession *C novascotica* occurs in the Moydart (Lower Ludlow age) and the Stonehouse (Upper Ludlow age) of Arisaig Nova Scotia (McLearn 1924) and has also been recorded from the Missenden Bore in England (Straw 1932) McLearn says (p 65) that *C novascotica* differs from *C striatella* in the development of a stronger median stria on the ventral valve which feature is also found in *C melbournensis* *C novascotica* has the same number of spines as *C melbournensis* but they are minute whereas those of the latter species are as long as three quarters of the length of the shell The surface of *C novascotica* has more numerous striae but forms with coarser ornament are known (McLearn 1924 p 66) The striae are flexuous in *C novascotica* but straight in *C melbournensis* These two species are distinct but closely approximate one another and provide another interesting connecting link between the faunas of this age in North America and Australia The spines of *C striatella* are heavy and short and set at an angle of about 45° to the hinge line whereas those of *C melbournensis* are long and slender and set at right angles to the hinge line The dorsal valve is definitely concave in *C striatella* whereas it is flat or almost so in *C melbournensis* *C striatella* is characteristically larger and more transverse than the Victorian species However the obvious similarity is striking

CHONETES (CHONETES) ROBUSTA Chapman

(Pl VIII, fig 5)

Chonetes robusta Chapman 1903, pp 76-77, pl XII, fig 8

TYPE MATERIAL —Two valves *in situ* (holotype), National Museum, Reg No 1417, about half of ventral valve, and most of dorsal valve, in indurated fine-grained sandstone from " North of Lilydale " (loc 3, *vide* Gill, 1940, p 258)

DESCRIPTION —Concave convex dorso-ventrally, 19 mm wide (but this not full width as one cardinal angle broken), and 12 mm long Outline sub semicircular Shell tumid with mesial sinus and a slight flattening on the cardinal angles, longitudinal profile rises about 6 mm above the plane joining the anterior and posterior margins of the shell Hinge-line mostly absent, but little less than greatest width of shell owing to slightly obtuse cardinal angles About thirty six fairly sharp, high ribs (counted in middle of shell) some bifurcating anteriorly Other specimens suggest that four strong spines on each side of the umbo (eight in all) is the normal number The outer spine in the type specimen has a slight inclination outwards The dorsal valve of the type specimen follows fairly closely the contours of the ventral valve, the greatest distance of separation being 1 5 mm Similar ornamentation to that on the ventral valve is preserved The ornamentation continues through to the interior of both valves As is the case with practically all fossils from the Lilydale district, only casts and moulds are preserved, the original shell material having been leached away

COMMENT —The study of specimens other than the type shows that the beak is inconspicuous scarcely projecting beyond the hinge line, the cardinal area is flat and well-developed, median septum short and narrow, teeth and muscle scars not observed The number of ribs has been noted to vary from 24 to 36 *C robusta* is closely allied to *C killarensis* sp nov, and *C cresswelli* Chapman

Occurrence —Besides the localities mentioned above, *C robusta* is known from " Wilson's " (loc 2), Hull-road, Mooroolbark (loc 13), and Syme's Tunnel Killara (loc 34)

CHONETES (CHONETES) CRESSWELLI Chapman

Chonetes cresswelli Chapman, 1903 pp 77 78, pl XII, fig 7

TYPE MATERIAL —Internal cast of ventral valve (holotype) in indurated mudstone from " North of Lilydale " (National Museum, Reg No 652)

DESCRIPTION —Shell approximately semi-circular in outline, being 7·5 mm long and 13 mm wide Ventral valve convex rising about 3 mm above the plane joining the anterior and posterior margins. Beak inconspicuous, scarcely projecting beyond hinge-line. Hinge-line straight and nearly equal to greatest width of shell. Cardinal angles approximately right angles. Teeth fine. Short, fine median septum 1·5 mm. long. Very narrow cardinal area. Some 40 fine, rounded ribs radiate from umbo, bifurcations increasing number of ribs at margin to about 54. Other specimens show spines at right angles to the hinge-line; they are finer than those on *C. robusta.* Conspicuous mesial sinus present. Faint traces of concentric lines of growth observed. Spines on a specimen from Hull-road, Lilydale (loc. 1) are figured (Pl. VIII., fig. 5).

Horizon.—Yeringian (Lower Devonian).

Comment.—This species is very closely related to *C. robusta,* the chief differences being (as Chapman remarked) in the altogether stouter build and fewer radii in *C. robusta.* The ribs are fine and rounded in *C. cresswelli* but high and sharp in *C. robusta.* Chapman also drew attention to the similarity between *C. cresswelli* and *C. australis* McCoy from the Middle Devonian rocks of Victoria. This is the more significant now in view of the much more closely approximated ages attributed to the Lilydale and Buchan Beds. *C. australis* occurs in great numbers in the Buchan and similar limestones, but no *Chonetes* has been found in the Cave Hill limestone beds at Lilydale. Brachiopods, except for *Atrypa reticularis,* are very rare at Cave Hill.

There is a close similarity between the chonetids of Victoria and those of the Devonian rocks of French Indochina. The Devonian of New Zealand, Eastern Australia, and Indochina appear to constitute a well-defined zone. Attention has already been directed to the similarity between certain trilobites in this zone (Gill, 1944). *Chonetes nongpoensis* (Mansuy, 1919, pp. 26-27, Plate V., fig. 4*a, b*) is very much like *C. cresswelli* Chapman. The general proportions of the shell are the same, the number of ornamenting ribs is about the same, and both have a well-marked mesial sinus, and short fine median septum. However, the ribs are rounded in *C. cresswelli* and raised and sharp in *C. nongpoensis,* as they are also in *C. robusta* which is a close variant of *C. cresswelli.* Unfortunately, the spines of *C. nongpoensis* are not known. As our knowledge stands at present, there is very little to separate *C. cresswelli* and *C. nongpoensis.* The specimens figured as *C. hardrensis* (Mansuy, 1921, Plate II., figs. 5*a-c*), *C.* cf. *margaritacea* (Mansuy, 1916*a*, Plate I., fig. 11), *C. indosinensis, C. lacroixi, C. lantenoisi,* and *C.* cf. *striatella* (Mansuy, 1916*b*, Plate VII., figs. 5-8), *C. seili,* and *C. mansuyi* (Patte, 1926) are comparable with our Victorian types. It is interesting to note the presence of a mesial sinus on some of these forms, and the orientation of the spines at right angles to the hinge-line, as in our species. *C. lantenoisi* and *C. lacroixi* have the long median septum noted in *C. taggertyensis.*

CHONETES (CHONETES) AUSTRALIS McCoy

Chonetes australis McCoy 1876 p 17 pl XXXV figs 3 5

Unfortunately the National Museum is unable at present to locate the type specimen of *C australis* Further description of this form and comment are therefore withheld in the hope that the type may be found As the specimen concerned is probably only misplaced and not really lost it is not proposed to choose a lectotype

Descriptions of New Species.

CHONETES (CHONETES) BOWIEAE sp nov

(Pl VIII figs 1 and 2)

TYPE MATERIAL —External cast and internal mould (syntypes) of a ventral valve in indurated fawn shale from Syme s Quarry Killara presented to the University of Melbourne Geology Department Museum (counterparts Reg Nos 1908 9) Collected by Mrs R Bowie after whom the species is named

DESCRIPTION —Shell 17 mm long (measured in one plane) and 19 mm wide at the widest part middle of the shell very tumid but practically flat on the cardinal extremities Cardinal angles obtuse Hinge line straight and less than greatest width of shell Cardinal area flat full width of hinge line parallel to plane of shell and about 1 mm wide Eight long evenly spaced spines fairly slender project from the cardinal margin at right angles to the hinge line longest spine preserved is 7 mm Beak projects a little beyond the hinge line Thin median septum about 4 mm long which is low at its anterior end where it rises from the floor of the shell and becomes higher towards its posterior end Interior of valve finely papillose around cardinal extremities there are traces of papillosity elsewhere on the internal cast which suggests that the whole interior of the valve was papillose The type specimen is crushed slightly by lateral pressure Teeth small and supported by dental lamellae almost parallel with the hinge line Between 50 and 60 fine rounded ribs (counted at the anterior margin) radiate from the umbo increases by bifurcation

HORIZON —Yeringian (Lower Devonian)

COMMENT —This species shares with *C productoida* and *C taggertyensis* general productid proportions It provides a further link between the faunules of Lilydale and Killara On the piece of rock containing the internal cast there is also a specimen of *Pleurodictyum megastomum* Dun and on the piece containing the external mould a pygidium of *Lichas* (*Euarges*) *australis* McCoy and *Beyrichia* sp can be seen

OCCURRENCE —Syme s Quarry (loc 35) Seville Quarry (loc 37) Melbourne Hill Lilydale (loc 7) and doubtfully at Hull road Lilydale (loc 1)

CHONETES (CHONETES) TAGGERTYENSIS, sp nov

(Pl VIII, figs 6 and 8)

TYPE MATERIAL —External cast and internal mould (syntypes) of a ventral valve in highly indurated fine-grained grey sandstone from Blue Hills, Taggerty, collected by Professor E S Hills and preserved in the University of Melbourne Geology Department Museum (counterparts, Reg Nos 1910, 1911)

DESCRIPTION —Shell 22 to 24 mm wide (one cardinal extremity is damaged and so an accurate measurement is not possible) 16 mm long profile rises 6 mm above the plane joining the anterior and posterior margins Valve very convex and flattened on the cardinal extremities ("oreillettes" of de Koninck) External mould shows 70 to 80 fine ribs at the anterior margin, increases by bifurcation The ribs scarcely show on the internal cast except for a strip 3 to 4 mm wide round the anterior perimeter of the shell This is an area outside the phenomenally large muscle scars and is finely papillate, slightly heavier papillae occur on the oreillettes Large flabellate incised (i e, raised in the mould) diductors extend three-quarters length of shell, enclosing incised adductors 4 5 mm long Beak inconspicuous projecting just beyond the cardinal line Cardinal area low at the extremities but rising to about 2 mm in the centre—very high for *Chonetes* Teeth very strong Shell thick Median septum strong and high at the cardinal end at least 6 5 mm long (between the cast and mould a little material has infiltrated and the septum may be longer than stated) There is the suggestion of a septum down almost the entire length of the shell In the other specimen figured (Reg No 1912, paratype Plate VIII, fig 6) the septum is seen to run practically the whole length of the big adductor scars No spines or spine bases can be distinguished on the type specimen, but in the associated specimen spine bases are present The only difference between the type specimen and the other is that the latter is a little more transverse in proportions, and the muscle scars are a little more deeply incised Both these variations are known to occur with increasing age in *Chonetes*

HORIZON —Probably Yeringian (Lower Devonian)

OCCURRENCE —Blue Hills, Taggerty, Victoria Professor Hills (1929) mentions the collection of *Chonetes* sp from Taggerty, but the specimens figured herein were collected subsequently by him

COMMENT —*Chonetes taggertyensis* has a number of affinities with *C sarcinulata* (Schlotheim) as figured by de Koninck (1847) in Pl XX, fig 15E There the same flabellate, incised muscle scars are seen with but faint trace of the ribs of the external ornament, a punctate margin is present showing more clearly the external ornament, and a very long median septum. The size of the muscles, the length of the septum, and the height of the ventral cardinal area are all phenomenal, and thus give more point to the comparison. However, the external ornament as described by de Koninck is quite different from that of our species, the ribs being many fewer in *C. sarcinulata,* practically all bifurcating, and doing so at about the same distance from the umbo. *C. sarcinulata* is one of the most characteristic fossils of the European Lower Devonian assemblage. *C. maoria* and *C. nigricans* (Allan, 1935; Shirley, 1938), from the New Zealand Lower Devonian, are of this same type, but the muscle area is smaller and the median septum shorter. However, a specimen of *C. maoria* in the National Museum, Melbourne, has a longer septum than that figured for the holotype. Allan says, "The general appearance of this species suggests such genera as *Plectambonites* Pander, but it probably belongs to *Chonetes.*" The generic position of *C. maoria* is confirmed by the presence of one spine base and probably a second on the specimen in the National Museum, Melbourne. Like *C. sarcinulata,* the New Zealand species is highly papillose on the interior surface except on the muscle scars. From Allan's figure, it appears that *C. maoria* has a mesial sinus like *C. cresswelli* and *C. robusta.* However, this is not present in the Melbourne specimen, nor is the "anterior margin somewhat sharply bent to produce a Leptaenid-like appearance." The latter may be due to pressure in the rock matrix.

C. taggertyensis is also like *C. unkelensis* (Dahmer, 1936, 1937), which is from the Siegenian of Unkel, and belongs to the *C. sarcinulata* gens.

CHONETES (CHONETES) PSILOPLIA, sp. nov.

(Pl VIII, fig. 15.)

TYPE MATERIAL.—Holotype consisting of a ventral valve in bluish-grey mudstone from Killara collected by Mr. F. Chapman, and lodged in the National Museum, Melbourne (Reg. No. 14519). The fossil is probably from loc. 34 (Gill, 1944).

DESCRIPTION.—Valve 13 mm. wide, 6·5 mm. long, and height (distance profile rises above plane joining anterior and posterior margins) about 1·5 mm. The cardinal angles are approximately right angles so that the outline of the valve is not exactly semicircular, but tends towards the sub-rectangular; the radius of the valve is 7·5 mm half way between the cardinal angle and the centre of the posterior edge of the shell. Valve somewhat flattened on the cardinal extremities and round the perimeter, forming a marginal flange comparable with that in *C. taggertyensis*. The muscle scars are not distinct, but inside the flange referred to there is a raised area on the cast where the ornament is less distinct and this may well be interpreted as incised muscle scars on the original shell. The external ornament consists of between 70 and 80 fine, somewhat sinuous, rounded ribs, increasing in number by bifurcation. Interior of valve finely papillate. Beak insignificant, not projecting beyond the hinge-line. Cardinal area about ·5 mm. wide, smooth, and fairly regular in width. Two spines set at right angles to the hinge-line are preserved, but neither is complete; one fragment is ·75 mm. long and the other 4 mm. These spines are very slender for a shell of this size—hence the trivial name. Impression of one tooth only (the other side is slightly broken away), and that is minute. Fine median septum 1·75 mm. long.

HORIZON.—Yeringian (Lower Devonian).

COMMENT.—This species is of the *C. sarcinulata* type with large incised muscle scars giving a differentiated margin to the interior of the ventral valve. The shell is of altogether lighter construction than *C. taggertyensis* (with which it may be compared), and the median septum is proportionately very much shorter. The spines are notable.

CHONETES (CHONETES) RUDDOCKENSIS, sp. nov.

(Pl. VIII., fig. 10.)

TYPE MATERIAL.—Holotype, consisting of an internal cast of a ventral valve in indurated olive-grey mudstone from Ruddock's Quarry (loc. 20), presented to the University of Melbourne Geology Department Museum (Reg. No. 1914).

DESCRIPTION.—Shell 7 mm. wide and 5·5 mm. long; longitudinal profile rises about 2 mm. above a line joining the anterior and posterior margins of the valve. Cardinal angles approximately right angles. Valve less convex on cardinal extremities. Beak insignificant. The two halves of the cardinal area form an angle of about 170°.

Ribs as seen in internal cast linear and of rounded cross-section; fine pitting between ribs, i.e., interior of valve finely papillose; about 40 ribs half way between anterior and posterior margins, and about 50 at the anterior margin; increase by bifurcation. What appears to be a linear median septum stretches nearly half way down the middle of the valve from the umbo. Cardinal area very narrow, and teeth not seen. Parts of two spines preserved on each side of the umbo; spines long and thin, set more or less at right angles to the hinge-line; longest spine present 3·5 mm.

HORIZON.—Yeringian (Lower Devonian).

OCCURRENCE —In the Lilydale District the new species is known from Ruddock's Quarry (loc 29, and from here the trivial name), Ruddock's Corner (loc 21), Edward-road Hill (loc 22), West of Lilydale Cemetery (loc 23), Victoria-road cutting (loc 24), "Devon Park" West (loc 25), "Devon Park" North (loc 26), North of Ruddock's (loc 39) Manchester-road, Mooroolbark (large cutting north of station—a new locality), Smale's Farm (on the west side of Edward-road, north of Ruddock's—a new locality) It has also been collected from the Kinglake District from near Strath Creek" by Professor E S Hills (Univ Geol Dept, Mus, Reg No 1916), a small *Pleurodictyum megastomum* is present on the same piece of rock

COMMENT —There is a good deal of variation in the group of shells at present included under *C ruddockensis* The type specimen is sub quadrate in outline with 40 to 50 straight linear ribs Another specimen noted is transverse in outline, with 30 to 40 stronger ribs which are somewhat sinuous Intermediate stages between the type and this latter specimen have been observed It is not clear yet how (if at all) this compact group should be subdivided but a detailed study of a large collection will no doubt solve the problem *Chonetes ruddockensis* has affinities with *C setigera* Hall, which has similar proportions ornament, and orientation of spines (at right angles to the hinge line) Our species has fewer and different spines Those of our species are remarkably long and slender, so much so that it is surprising that so many have been preserved The waters in which the enclosing sediments were laid down must have been fairly quiet an inference which may also be made from the fineness of those sediments One shell from Ruddock's Quarry 4 5 mm long has preserved a spine 8 mm long, and it ends abruptly suggesting that it was even longer originally In the European facies *C ruddockensis* seems to find its affinities with *C soror* Barrande

CHONETES (CHONETES) KILLARENSIS, sp nov

(Pl VIII fig 14)

TYPE MATERIAL —Internal cast of a ventral valve (holotype) in bluish-grey indurated mudstone from Syme's Tunnel, Killara (loc 34), presented to the University of Melbourne Geology Department Museum (Reg No 1915)

DESCRIPTION —Shell 20 mm wide and 17 mm long, evenly tumid except for mesial sinus and a slight flattening on the cardinal angles, longitudinal profile rises 5 mm above the line joining the anterior and posterior margins of the shell Mesial sulcus about 1 mm deep, and about the width of five ribs Cardinal angles approximately 115° Cardinal area nearly straight, but the two halves of the line form a vertex at the umbo Ribs (on the internal cast) sharp and high, with bifurcations but no intercalations, number 34 half way between the anterior and the posterior margins, and 37 at the anterior margin, slight punctation between the ribs right in the cardinal angles. Probably ten very short, fine, somewhat sinuous spines ranged along the cardinal margin, perpendicular to the hinge-line, most complete spine present 1.5 mm. long. Cardinal area very narrow. Beak small, distinct, projecting slightly beyond the hinge line. Median septum about 3 mm. long, not ending abruptly but tapering away on to the floor of the shell; septum about 1/6th mm. wide. Teeth strong.

HORIZON.—Yeringian (Lower Devonian).

COMMENT.—This new species is comparable with *C. robusta* which occurs in the same beds. The spines are long, straight, and strong in *C. robusta*, but short, fine, and sinuous in *C. killarensis*.

OCCURRENCE.—A form very similar to *C. killarensis* occurs in the soft fawn mudstones of Melbourne Hill, Lilydale (loc. 7). The spines are of the same kind but the ribs are more numerous, and the mesial sinus very shallow. However, for the time being it is included in this species. In any case the fossil constitutes another interesting link between the beds at Killara and those at Lilydale.

CHONETES (CHONETES) PRODUCTOIDA sp. nov.

(Pl. VIII, figs. 7 and 12.)

TYPE MATERIAL.—Internal cast of a ventral valve (holotype) in indurated fine-grained, fawn sandstone from Lilydale, Victoria. Collected by Reverend A. W. Cresswell, M.A., from "North of Lilydale" (loc. 3), and presented to the National Museum, Melbourne (Reg. No. 14520).

DESCRIPTION.—Length of shell (measured in one plane and not following obesity of shell) 17 mm., and width 21 mm., longitudinal profile rises about 7 mm. above a line joining the anterior and posterior margins of the shell. Shell very tumid, but fairly flat on the cardinal margins, simulating productoid proportions—hence the trivial name. Cardinal angles damaged, but probably slightly obtuse. Hinge-line straight. Ribs (on internal cast) sharp and high, but have the appearance of being worn off on the anterior part of the type specimen (compare other figured specimen, National Museum, Reg. No. 14521—hypotype), number 31 half way between the anterior and posterior margins, increases by bifurcation. Umbonal area highly arched and overhangs hinge-line productid-fashion. The spine bases present indicate eight strong spines along the cardinal margin, probably at right angles to the hinge-line. Cardinal area narrow. Median septum 3 mm. long, ending fairly abruptly; high, and about ½ mm. wide. Teeth strong.

HORIZON.—Yeringian (Lower Devonian).

COMMENT.—This new species is very similar in external appearance to *C. hemispherica* Hall of the Upper Helderberg in North America, from which it can be distinguished readily by its fewer ribs. *C. productoida* is not merely the gerontic stage of *C. robusta* which also it closely resembles. Gerontic specimens of the latter are equally obese but do not have the high umbonal area and recurved beak of *C. productoida.* Moreover, *C. robusta* has a mesial sinus at all stages in its development, and the shell is not so flattened on the cardinal angles. It is interesting to note in this species (as also to certain extent in *C. bowieae*) the attainment of a *Productus*-like form.

CHONETES (CHONETES) GASKINI, sp. nov.

(Pl VIII., fig. 9.)

TYPE MATERIAL.—A ventral valve preserved in hard, bluish limestone from the scarp along Old Hut Creek, Bindi District, Gippsland (see map, Gaskin, 1943). The species is named after Mr. A. J. Gaskin, who collected the type specimen, which is now in the University of Melbourne Geology Department Museum (Reg. No. 1913).

DESCRIPTION.—Ventral valve 4 cm. wide; greatest length preserved in type specimen (which is incomplete) 2 cm.; but a complete valve would be longer; height (distance profile rises above plane joining anterior and posterior margins) about 1·25 cm. Cardinal margin rises slightly at umbo, which is not prominent. One spine only preserved on the cardinal margin. It is ½ cm. long, straight, slightly turned outwards, and possessing fine annulations (see photomicrograph, Pl. VIII., fig. 11). The valve is flattened on the cardinal extremities. The external ornament consists of 40 ribs which are much stronger in the centre of the shell than they are on the cardinal margins. The ribs do not all commence at the umbo, some beginning at locations along the cardinal margin, the furthest out starting at a point 13 mm. from the umbo. The ribs in cross-section form low arches, and the interspaces are about equal in width to the ribs.

HORIZON.—Bindi Limestone (Middle Devonian).

COMMENT.—This large new species is phenomenal for its possession of an annulated spine. It is clearly not an artefact, nor is it a small annulated shell like *Tentaculites* resting against the cardinal margin of the *Chonetes*. As far as the author is aware, an annulated spine on a *Chonetes* has not been described before.

Discussion of the Genus Anoplia.

Family CHONETIDAE Hall and Clarke, 1895.

Genus **Anoplia** Hall and Clarke, 1892.

Genoholotype: *Leptaena nucleata Hall*, 1857, 10th Rept. New York State Cabinet, p. 47 (quoted from *Fossilium Catalogus*).

Etymology of Generic Name.—Greek anoplos = unarmed.

Diagnosis of Genus.—Small chonetoids possessing a smooth or almost smooth surface, but without spines on the ventral cardinal margin. Ventral median septum, terminating abruptly.

Comment.—As far as the author is aware, only four species have been referred to this genus, viz.:—

Anoplia nucleata (Hall) Lower and Middle Devonian—Oriskany of Ontario and New York. Amazon. Onodaga and Grand Grève (Caley, 1940). Middle Devonian of Maryland. Lower Devonian of Moselle (Dahmer, 1928, 1930).

Anoplia helderbergiae Schuchert. Lower Devonian—Helderberg Formation.

Anoplia australis Gill. Lower Devonian of Victoria—Yeringian Series.

Anoplia withersi Gill. Ditto.

When Hall and Clarke erected the genus, the absence of spines was regarded as its chief feature—hence the name meaning "unarmed." However, *A. helderbergiae* was found to possess spines like *Chonetes*, but Schuchert (1913) has argued that the genus is a good one to embrace "the early smooth or slightly lamellose, highly convex, small chonetoids with a ventral median septum." The ventral median septum is a common feature of *Chonetes*, and the Victorian forms of *Anoplia* at least are not highly convex. Smooth *Chonetes* are also known. Thus, none of the features named by Schuchert can now be said to be characteristic of *Anoplia* alone. There seems to be no course left but to keep to the original definition of the genus as small, smooth chonetoids without spines, and refer *A. helderbergiae* to *Chonetes*. It is interesting to note that smooth forms have arisen twice in the *Chonetes* line of evolution, viz., *Anoplia* in the Lower Devonian, and smooth *Chonetes* (*C. glaber*) in the Upper Carboniferous.

Anoplia possesses reversionary characters. The term "reversion" is here used in distinction from the term "atavism," and as defined by Crew (1925, p. 3). It may be assumed that the genus *Chonetes* "degenerated" in one direction to *Anoplia*, just as in another it "advanced" to *Productella* and *Productus*. The reversionary characters are:—

(1) Loss of ornament.—The surface of the shells is smooth in *Anoplia*, or almost so. Schuchert writes, "The smooth forms of *Chonetes* are not descendants of *Anoplia*, but are derived from

associated finely striated forms of the former genus Apparently both the smooth *Chonetes* and *Anoplia* arose from finely striated *Chonetes* but at different times Hall (1892 Plate 15*a* fig 18) figures a specimen of *A nucleata* with faint ribbing which may be regarded as an indication of the ornament carried by its ancestors An example of similar genetic interest is a specimen of *A australis* collected by Mr R B Withers in the Kinglake District (Plate VIII fig 4)

(2) Loss of Spines—Hall and Clarke made this the chief diagnostic character of their genus and it is indeed notable among a whole series of spinose forms which were an important element in marine faunas for over 150 million years It is notable also for the reason that the general tendency with the effluxion of time was for the increase and not decrease of spinosity

Notes on Species Previously Described

ANOPLIA AUSTRALIS Gill

Anoplia australis Gill 1942 pp 38 39 Pl IV fig 8

This species is very characteristic of the Ruddock s Quarry horizon of the type Yeringian Beds at Lilydale It occurs in great numbers at Ruddock s Quarry along with equally great numbers of *Chonetes ruddockensis* sp nov and *Stropheodonta bipartita* (Chapman) On the other hand it is very rare in the highest beds of the series only one specimen having been collected for instance from Hull road Mooroolbark The Ruddock s Quarry horizon has been traced south to Mooroolbark where *A australis* has been collected from a large cutting on Manchester road north of the railway station

The two subsidiary ridges in addition to the median septum are of interest in this species Certain parallels to these can be found in other genera For example *Sowerbyella gracilis* Jones (1928 p 473 Plate XXIV fig 22) possesses a similar complement of ridges also *Chonetes cumbrensis* Garwood (1931 p 148)

Further Occurrences—In addition to localities previously named *A australis* has been collected from the quarry north of Syme s Homestead Killara (loc 32) and from Jerusalem Creek (Geol Surv Vic Reg No 18218)

ANOPLIA WITHERSI Gill

Anoplia withersi Gill 1942 p 39 Pl IV fig 7

Usually *A australis* is the dominant form where both the Victorian species are present together An exception to this has been noted at Jerusalem Creek east of Eildon Weir The numbers given with the following new records of occurrence are registered numbers of the Geological Survey of Victoria —

Nos 18222 and 18223—light fawny grey sandstone from 70 chains S E of the junction of Jerusalem and Barnwell s Creeks Jamieson Q S

Nos 18218 and 18227 from spur between Wilson s and Barnwell s Creeks

Variations have been noticed in *A withersi* in the length of the septa in the prominence of the beak and in the general outline of the shell

Stratigraphical Considerations.

The earliest reference to chonetids in Victoria is probably that made by Blandowski in 1855 when he figured some undescribed fossils from the McIvor Goldfield His plate opposite page 223, fig 359 is evidently a *Chonetes*

The named species of Victorian *Chonetes* were described by McCoy (1876) and Chapman (1903) To these the present writer has added two species of *Anoplia* (1942) and the new species of *Chonetes* described in this paper These amount to fourteen chonetid species in all Material has been collected which indicates the presence of a number of further new species but the specimens are not good enough on which to found new species The Silurian and Devonian rocks of Victoria are rich in chonetids Some occur in gargantuan numbers e g *Chonetes ruddockensis C australis* and *Anoplia australis* also to a less extent *C melbournensis C cresswelli* and *A withersi*

SUBDIVISION OF THE YERINGIAN SERIES IN THE TYPE AREA

The Victorian chonetids are good index fossils *C melbournensis* is strictly Melbournian *C australis* and *C gaskini* strictly limited to the Buchan and Bindi Beds and the rest strictly Yeringian (Lower Devonian) Divisions within the Yeringian Series can be satisfactorily made on the basis of these fossils and the following subdivision is proposed (for structure *vide* Gill 1942) —

1 LOWER YERINGIAN—to be recognized by the presence of *Chonetes ruddockensis Anoplia australis* and *Stropheodonta bipartita* (It has been noted that there is a *Stropheodonta bipartita* in the Devonian beds of North America (Swartz 1941) but it belongs to *Leptostrophia* which sub genus is now accorded generic rank As our *S bipartita* belongs to *Stropheodonta sensu stricto* there is no need to change the name) These are all prolific forms and their occurrence in strength may be always taken as an indication of the presence of this sub division

2 UPPER YERINGIAN—to be recognized by the presence of *Chonetes cresswelli, C robusta,* and *C killarensis*

These subdivisions are in keeping with what we know of the Yeringian faunules as a whole Of course, such subdivisions must be regarded as tentative in that further subdivisions will probably become possible as our knowledge of these beds and their faunules increases However, this distinction between Upper and Lower Yeringian will help considerably in the classification of strata elsewhere in relation to the type Lilydale beds For instance, the grey mudstone beds north of Tommy's Hut with plentiful *S bipartita,* and the bluish indurated mudstones of West Kinglake with *A australis* the reddish mudstones of Yellingbo with *S bipartita* and *C* cf *ruddockensis,* the grey mudstones at Christmas Hills with *S bipartita,* and similar beds at "Two miles below Simmond's Bridge Hut on the Yarra," may all be classified as Lower Yeringian the bluish-grey mudstones at Killara (locs 34 and 35) may be classified as Upper Yeringian The strong affinities between *C taggertyensis* and the Upper Yeringian form *C psilophia* suggests an Upper Yeringian classification for the beds in the Blue Hills in which *C taggertyensis* occurs No *Chonetes* have yet been described from the Heathcote Beds but the collections made by Dr Thomas have not yet been studied

Chonetes ruddockensis and *Stropheodonta bipartita* are entirely absent from the Upper Yeringian beds of the Lilydale District One specimen only of *Anoplia australis* has been found at Hull-road Mooroolbark (loc 13), and one only at North of Lilydale (loc 3), whereas both species are prolific in the Lower Yeringian As far as our knowledge goes, any of the three forms named as characteristic of the Lower Yeringian, if present in strength, may be taken as indicative of a Lower Yeringian horizon The three forms given as characteristic of the Upper Yeringian have not been found outside those beds, so apparently any of the three species if present at all is an indication of that horizon

Ruddock's Quarry (loc 20) is named as the type locality for the Lower Yeringian The olive grey indurated mudstones (with occasional still harder sandstone bands) found there can be traced from Mooroolbark through the Ruddock's Quarry area (where pitch affects the strike), and north towards Yarra Glen Hull-road, Lilydale (loc 1), is named as the type locality for the Upper Yeringian There in whitish and reddish soft mudstones, *C robusta* and *C cresswelli* have been collected, and *C killarensis* occurs in the adjacent locality of Melbourne Hill, Lilydale (loc 7)

THE JORDANIAN SERIES —The next question is the relation of these forms to the Jordanian Series (Gill, 1941) Except for a few ubiquitous forms, the faunas of the Melbournian and

Yeringian are mutually exclusive, although they are both of littoral facies. There would not be this faunal break if the two series constituted a continuum in time. There must be a time-break between the two series, and this is occupied by the Jordanian Series. This series (as known at present) is pelagic, but not just the pelagic facies of a part of the Melbournian or Yeringian. Littoral forms are rare in the Jordanian, and so chonetids are not to be expected. A brachial valve which may be a *Chonetes* (collected by Dr. I. Cookson at McMahon's Creek) is the only chonetid found so far in the series.

The Melbournian beds contain graptolites of Lower Ludlow age (Jones, 1927). The Yeringian beds are Lower Devonian (Gill, 1942), and may even extend up into the Middle Devonian (Ripper, 1938, Hill, 1939, 1943). Thus there is a lacuna of Upper Ludlow age, which must be the age of the Jordanian beds. A *Posidonomya* common at McMahon's Creek (east of Warburton) is very similar to *P. eugyra* from étage E. of Bohemia, which is equivalent to the Upper Ludlow.

CORRELATION WITH OVERSEAS DEPOSITS.—There are interesting parallels between the Victorian chonetids and forms described from the classic series of Europe and North America; also from beds in Indochina. These may be summarized as follows:—

Stratigraphical position in Victoria.	Victorian Species.	Overseas Species.	Stratigraphical position Overseas.
Melbournian	*Chonetes melbournensis*	*C. novascotica* of Nth America and Europe	Ludlow.
Yeringian ..	*C. productoida* ..	*C. hemispherica* of Nth. America *C. verneuili* of Europe	Upper Helderberg, etc.
Yeringian ..	*C. cresswelli* .	*C. nongpoensis* of Indochina	(Lower) Devonian
Yeringian .	*C. ruddockensis*	*C. setigera* of Nth. America *C. soror* and *C. C. embryo* of Europe	Marcellus Waverley
Yeringian .	*C. taggertyensis* ..	*C. sarcinulata* ..	Lower Devonian, "most abundant in the Upper Siegenian"
		C. unhelensis ..	Uppermost L. Dev.
		C. maoria ..	Lower Devonian of N Z., "Siegenian or Lower Coblenzian."
Yeringian ..	*Anoplia australis* ..	*A. nucleata* ..	L. Dev. of Moselle; Oriskany and Onondaga of Nth. America.

It should be noted that the above comparisons are not all of equal value. *C. melbournensis* and *C. novascotica* are very similar; so also are *C. taggertyensis*, *C. maoria*, and *C. sarcinulata*. On the other hand, the comparisons between *C. ruddockensis* and *C. setigera*, and between *C. productoida* and *C. hemispherica*, are based on striking likenesses in external form. In both the cases quoted the important internal characters are not known.

Further there is no great likeness between our species of *Anoplia* and *A nucleata* but as the genus is so rare in number of species there is no doubt significance in its presence

The Lilydale Beds which constitute the type beds of the Yeringian Series are very thick Although the thickness already given on the evidence available (Gill 1942) will very likely be reduced as our knowledge of the structure is increased there nevertheless is certainly a great thickness of beds involved It is possible that the mudstones and sandstones of the Yeringian Series cover the whole of Lower Devonian time but a great thickness of beds below the Ruddock s Quarry horizon is apparently quite unfossiliferous and the limits of the series have not yet been precisely defined The writer prefers to wait till the faunules of the Yeringian type area have been further worked out before drawing any close correlations with the classic over seas series

Acknowledgments.

The author wishes to express his appreciation of the kind co operation of the University of Melbourne Department of Geology (through Professor E S Hills and Dr F A Singleton) the National Museum (through the late Mr D J Mahony Director and the palaeontologist Mr R A Keble) and the Geological Survey of Victoria (through the Director Mr W Baragwanath) The photographs were taken by Mr L A Baillot of the Melbourne Technical College

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Description of Plate.

PLATE VIII.

(No photographs are retouched.)

FIG. 1.—*Chonetes bowieae*, sp. nov., internal cast of ventral valve (syntype) × 2 approx.

FIG. 2.—*Chonetes bowieae*, sp. nov., external mould of ventral valve (syntype) same size approx.

FIG. 3.—*Chonetes productoida*, sp. nov, internal cast of ventral valve (hypotype) × 1.5 approx.

FIG. 4—*Anoplia australis* Gill. Specimen from Kinglake showing ribbing (enlarged).

FIG 5—Spines of *Chonetes cresswelli* Chapman Specimen from Hull-road, Lilydale.

FIG. 6—*Chonetes taggertyensis*, sp nov, internal cast of ventral valve (paratype) × 2 approx.

FIG 7—*Chonetes productoida*, sp. nov, internal cast of ventral valve (holotype) × 1·5 approx.

FIG 8—*Chonetes taggertyensis*, sp. nov, internal cast of ventral valve (syntype) × 2 approx.

FIG 9.—*Chonetes gaskini*, sp nov. ventral valve (holotype), same size. Note spine.

FIG. 10—*Chonetes ruddockensis*, sp. nov., internal cast of ventral valve (holotype) × 4 approx. Note long spine.

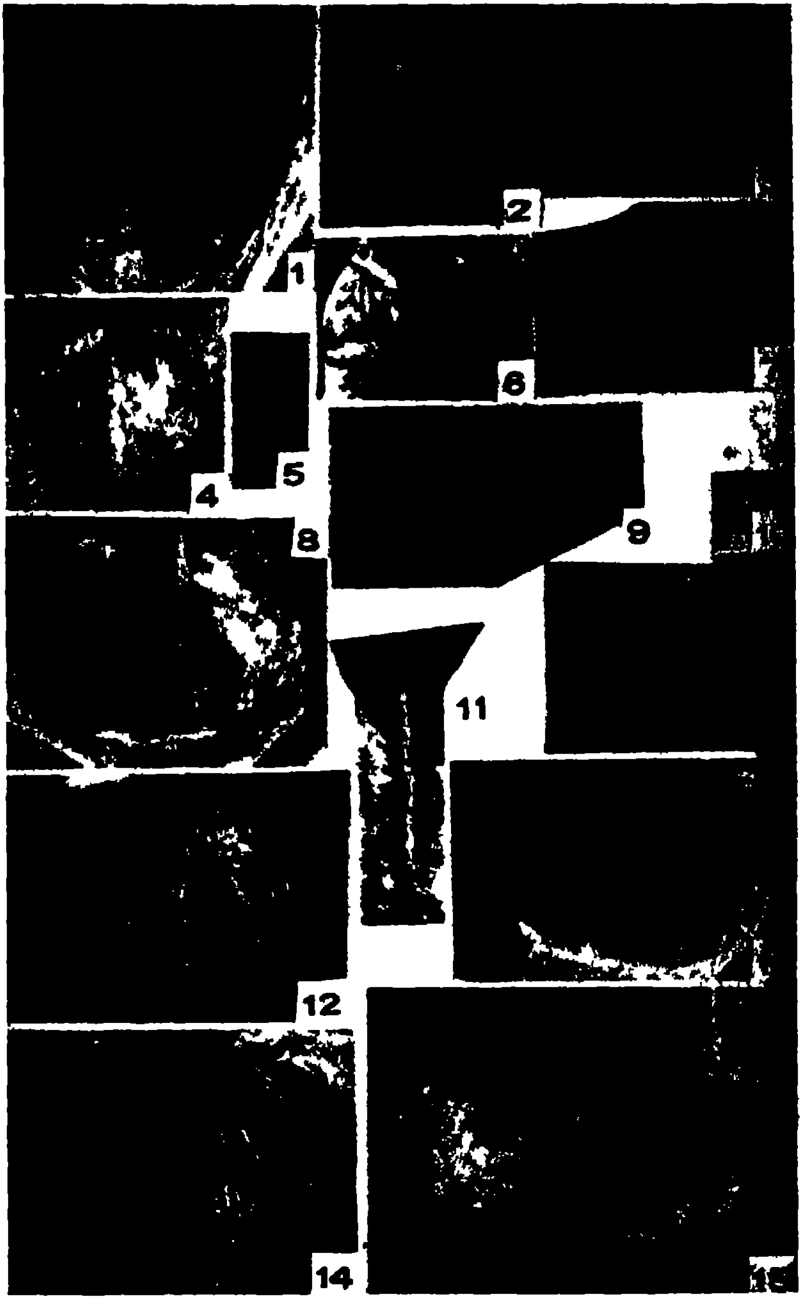
FIG 11—Photomicrograph of spine of *Chonetes gaskini*, sp. nov. (*vide* fig. 9). Note annulation where spine joints shell, and a series of annulations at the outer end

FIG 12.—*Chonetes productoida*, sp. nov., internal cast of ventral valve (holotype) showing spine bases and medium septum.

FIG. 13—*Chonetes taggertyensis*, sp. nov, external mould (syntype) showing external ornament, × 2 approx.

FIG. 14.—*Chonetes killarensis*, sp. nov., internal cast of ventral valve (holotype) × 2 approx.

FIG. 15.—*Chonetes psilopia*, sp. nov., internal cast of ventral valve (holotype) × 4 approx.



Chonetes and Anoplia

[Proc. Roy Soc Victoria 57 (N S) Pts I-II 1945]

Art VII—*The Glauconitic Sandstone of the Tertiary of East Gippsland Victoria*

By A B EDWARDS

[Read 14th December 1944 issued separately 10th December 1945]

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Abstract

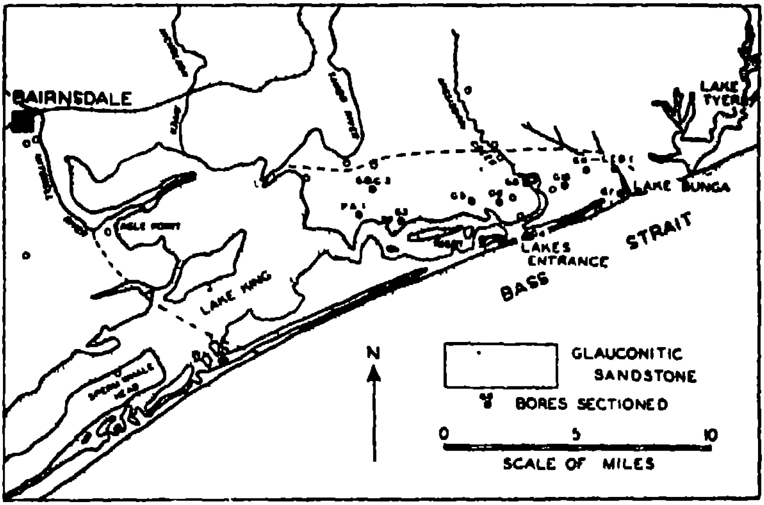
The glauconitic sandstone formation that occurs at depth in the Tertiary strata of East Gippsland Victoria consists of grains of altered glauconite in a felspathic sandstone which has a cement of glauconitic mud The glauconite grains are largely derived from the alteration of biotite flakes They often show open shrinkage cracks that developed at an early stage of lithification Much of the glauconite is altered to a ferruginous clay like substance The alteration occurred during deposition and prior to lithification and is not a weathering effect although it resembles the alteration of glauconite caused by weathering

The air dried rock shows abnormally high porosity and low permeability Impregnation of the rock with coloured canada balsam reveals that the natural cement of the rock is highly porous in an air dried state the pore spaces being of capillary dimensions The high porosity appears to have been induced by air drying of the rock and may not be a feature of the rock *in situ*

Introduction

The petroliferous glauconitic sandstone that occurs in the Lakes Entrance district of Gippsland has been described briefly by Crespin (1943 p 32) In this note it is proposed to elaborate several features of petrological interest exhibited by this rock

The glauconitic sandstone occurs at or near the base of the Tertiary strata in this part of Victoria above a bedrock of granitic and metamorphic rocks In places it rests directly on the bedrock, but mostly it is separated from it by a thickness of from 20 to 200 feet of Tertiary sediments. The glauconitic sandstone does not outcrop. Its limits have been defined by drilling (fig. 1). It extends from Lake Bunga in the east to Eagle's Point in the west, a distance of about 20 miles, and from the coastline northwards (inland) for a distance of from 3 to 5 miles. Its south-western limit is between Rigby Island and Sperm Whale Head. The sandstone is oil-bearing over an area of about 8 square miles in the vicinity of Lakes Entrance.



The glauconitic sandstone lies at a depth of from 960 to 1,416 feet below sea-level, the depth increasing towards the south or south-east at about 1 in 400. It has an average thickness of about 30 feet in the 40 bores that have intersected it. The maximum thickness recorded in any bore is 60 feet, in the No. 2 bore of the Lakes Entrance Development Co., near Lake Bunga in the parish of Colquhoun.

Crespin (1943) classifies the glauconitic sandstone as the lower lithological unit in the Janjukian stage of the Middle Miocene in Gippsland. It overlies Miocene strata of the Anglesean stage, and passes upwards into sandy micaceous marls which contain grains of glauconite in their lower beds.

A petrological examination of specimens from the core of the No. 10 Government bore at Lakes Entrance has been issued by Dr. F. L. Stillwell, under the title "Glauconitic Sandstone from

No. 10 bore, Lakes Entrance", as Mineragraphic Report No. 308, of the Council for Scientific and Industrial Research. This examination was made at the request of Dr. H. G. Raggatt, Director of the Mineral Resources Survey. Porosity measurements made by Mr. R. F. Thyer, of the Mineral Resources Survey, on dried specimens from this core had given porosities as high as 35 per cent., which is much in excess of that recorded for most oil sands, while permeability measurements on the same specimens had shown them to have low permeability. The petrological examination was sought in the hope that it might provide some explanation of this anomaly, but only a partial explanation was arrived at.

This, and other peculiar features of the glauconitic sandstone revealed by this examination, indicated that a more extensive petrological study of the formation as a whole was justified. To this end material from all the available cores of other Government and private bores was examined. This material was made available by the kindness of Mr. W. Baragwanath, then Director of the Geological Survey of Victoria.

My thanks are also due to Dr. M. Glaessner, Dr. W. D. Osborne, Mr. J. Montgomery, and Professor E. S. Hills, for helpful criticism of the manuscript. The original petrological examination (Mineragraphic Report No. 308) was made in collaboration with Dr. F. L. Stillwell.

Petrology.

In the hand specimen, the glauconitic sandstone is brownish-green to brown, and uniformly fine-grained, except for occasional rounded grains of iron-stained quartz, or quartzite, a millimetre or more in diameter. Occasionally these coarser grains are sufficiently numerous to give the rock a grit-like appearance over a thickness of about half an inch. A freshly broken surface is minutely pitted owing to the breaking out of the glauconite grains from the matrix. The grains that remain in the surface look like minute pellets of limonite. Some specimens contain sparsely distributed shells, such as Turritelloids, 1 to 2 cm. long. These are generally filled with glauconitic sandstone, though a very occasional shell may be only partly filled.

Thin sections were prepared of representative samples of the sandstone from the eleven available bore cores of the bores that have encountered this formation. They are Government bores Nos. 3, 4, 5, 6, 7, 8, 10, 11, and Lakes Entrance Development Co. No. 2 bore, all in the parish of Colquhoun, Point Addis Co. No. 1 bore, and Gippsland Oil Co. No. 3 bore, in the parish of

Bumberrah These eleven bores are so spaced as to cover most of the extent of the glauconitic standstone formation (fig 1) From most of these cores two samples some feet apart were sectioned but from No 10 Government bore parish of Colquhoun ten sections were cut representing the horizons at 1 261 63 feet 1 265 67 feet 1 267 70 feet 1 270 72 feet 1 275 76 feet 1 277 78 feet 1,291 94 feet and 1 294 1 300 feet The close similarity between all the specimens sectioned leaves little doubt that they give a true picture of the composition of the sandstone formation

Some of the bore cores had been air dried before they were received others had been stored in sealed tins Some had been drilled dry and the drill cores were too hot to hold in the hand when raised others had been drilled wet and were not heated unduly by the drilling The differences in drilling practice and storage do not appear to have affected the state of the glauconite or the structures of the rock

The specimens with one exception were too friable to section without previous impregnation Since glauconite undergoes dehydration when heated above 70°C (Ross 1926 Takahishi 1939) care was taken not to heat them unduly The specimens were soaked in a thin cold solution of canada balsam in xylol and dried in an air oven at 30°C The cemented material was then mounted and sectioned in the usual way With some sections it was necessary to coat the ground surface with the balsam xylol solution and dry at 30°C several times before a smooth surface suitable for mounting could be obtained the same process had to be repeated during the final stages of grinding some of the thin sections Wet specimens were dried for 24 hours at 30°C in the air oven prior to impregnation

The thin sections reveal that the specimens from the different bores and from different horizons in the same bore are closely similar in mineral composition and texture but vary slightly in the proportion of the various constituents They consist of numerous smooth surfaced oval and sub angular grains of glauconite dispersed through a fine grained felspathic sandstone which consists of quartz orthoclase oligoclase and abundant biotite with minor amounts of muscovite pyrite iron oxides leucoxene tourmaline zircon apatite and in places a carbonate mineral cemented together by a greenish to greenish yellow isotropic substance presumably a glauconitic mud In some sections this glauconitic mud is largely replaced by the carbonate mineral which is presumably dolomitic since it is not stained by treatment with silver nitrate and potassium chromate

Occasional tests of foraminifera (consisting of calcite) are usually present generally with a filling of green glauconitic material

The quartz and felspar occur chiefly as angular to sub angular grains from 0 1 x 0 1 mm to 0 05 x 0 05 mm in size In some sections the majority of the grains are water worn In addition there is in every section a few coarser limonite coated and well rounded fragments of quartzite quartz or felspar a millimetre or more in diameter dispersed through the fine grained rock In some sections there are also occasional well rounded pellets of fine grained mudstone more or less glauconitized of about the same dimensions (Plate IX fig 7) These may be of coprolitic origin Many of the numerous biotite flakes are slightly chloritized or glauconitized They vary in size from 0 3 x 0 1 mm to 0 1 x 0 05 mm

These together with the less common minerals are set in an amorphous or cryptocrystalline greenish to yellowish susbtance which occurs as films of cement between the individual grains where they are closely packed (Plate IX figs 1 and 2) and as a base through which they are studded in sections in which they are widely spaced In some sections the width of the green cement separating the individual grains is as much as 0 05 mm The material appears to be a glauconitic mud and generally forms the filling of the tests of foraminifera in the rock

The proportion of carbonate varies greatly from section to section In some it occurs only as the tests of the occasional shells and foraminifera but in others it is an abundant constituent of the matrix of the rock largely replacing the green base In several of these sections it occurs chiefly as well formed and slightly iron stained rhombohedra of dolomite about 0 05 x 0 03 mm either as isolated crystals or in clusters This well crystallized dolomite is presumably of diagenetic origin

THE GLAUCONITE

The glauconite grains are occasionally 1 0 mm across but are generally between 0 5 x 0 3 mm and 0 2 x 0 2 mm Some of the grains are green or greenish yellow but the majority of grains are yellow yellowish brown or reddish brown and some closely resemble limonite in appearance indicating that they are altered forms of normal green glauconite comparable with the alteration products of glauconite described by Gildersleeves (1932) from the weathered Eocene greensands of Virginia and Maryland U S A

Some of the altered glauconite grains are zoned, the outer zone being generally darker than the core, though some show a narrow fringe of greenish-yellow material around the brown zones. In some sections a number of the grains have a green or greenish-yellow core with a yellow or brown margin.

Many of the grains have smooth, rounded surfaces, and some have a smooth, mammillated surface. Others are angular to sub-angular. Some of the rounded grains are nearly circular, but the majority are oval. Occasional grains contain inclusions of quartz that are finer-grained than the quartz of the sandstone.

Many of the glauconite grains reveal evidence of shrinkage. Sometimes the shrinkage cracks extend more or less radially into the grains (Plate IX., fig. 3). Many of the grains have shrunk away from the enclosing matrix (Plate IX., fig. 1) or from a narrow rim of glauconite strongly cemented to the matrix. Some zoned grains show shrinkage cracks at the margin of successive zones. These shrinkage cracks appear to be similar to the fractures in weathered glauconite figured by Gildersleeves (1932). For some grains, the shrinkage cracks may constitute as much as 30–40 per cent. by volume of the grain.

The shrinkage cracks are an original structure of the glauconite, and are not due to heating during drilling, or drying out of the specimens. This is proved by the fact that, in several sections, grains of altered glauconite occur in which shrinkage cracks have developed, but have been infilled with the green or greenish-yellow material that forms the cement between the grains of the sandstone (Plate IX., Fig. 2). The pattern of the shrinkage cracks (Plate IX., fig. 2) leaves little doubt that they arise from the drying out of an originally gelatinous substance. Similar shrinkage cracks, though not so strongly developed, characterize many grains of unaltered green glauconite found at higher horizons in the Gippsland bores.

The shrinkage probably occurred during lithification. Glauconite grains which have shrunk away from the enclosing matrix (Plate IX., fig. 1) or from a narrow rim of the grain strongly cemented to the matrix, could only have done so after the rock was more or less consolidated. Where the cracks have been infilled with glauconitic mud, either the shrinkage cracks occurred at an early stage of lithification and the glauconitic mud was squeezed into the opening or carried in by connate waters, or the glauconitic mud entered cracks which had developed during deposition. In sections with abundant carbonate, the carbonate rarely, if ever, occurs in the shrinkage cracks of the glauconite grains, though in such sections the cracks are often filled with green glauconitic mud. Since the carbonate is probably diagenetic in origin, the filling of the shrinkage cracks, and hence their formation must have taken place either at an early stage of lithification or during deposition. The latter seems unlikely because the fractured parts of grains so broken by shrinkage cracks would readily have separated.

FORMATION OF THE GLAUCONITE.

As noted by Crespin (1943, p. 33), much of the glauconite appears to have formed from the alteration of biotite in the manner described by Galliher (1935). All stages of the transition from biotite to glauconite can be seen in the thin sections. The biotite first swelled in a direction at right angles to its cleavage planes. Commonly the swelling was greater on one side of the flake than on the other, so that the swollen flake became curved (Plate IX., fig. 4). Where this unequal swelling was pronounced, the biotite flake became fan-shaped, the cleavage traces corresponding to the ribs of the fan (Plate IX., fig. 5). In this expanded state, the biotite retains its pleochroism and colour. Takahashi (1939, p. 506) indicated that the swelling is caused by hydration of the biotite, which leaves it in a gelatinous state.

At this stage glauconite developed along the cleavage planes so that the biotite became parti-coloured brown lamellae alternating with green (fig. 8); the glauconite spread laterally into the biotite until the whole of the expanded flake was converted to glauconite, in which faint traces of the biotite cleavage still remain (Plate IX., fig. 6). During this transition, the lamellae of biotite between successive cleavage planes sometimes splayed apart, and when the splayed margins became slightly rounded, they gave the glauconite a mammillated outline (Plate IX., fig 1) that might be mistaken for the cast of a foraminifera. As the gelatinous glauconite dried, it shrank, developing rounded edges and shrinkage cracks.

The well-rounded outlines of many of the glauconite grains, and of some of the expanded biotite flakes, contrast strongly with the distinctly angular form of many other grains of glauconite and expanded biotite (Plate IX., fig. 1). The rounding may be due to attrition during deposition or, more probably, as Galliher (1935) suggests, to passage through the intestines of worms while in a gelatinous condition.

The zoned character of some of these grains in their altered state is presumably due to the inward progression of alteration rather than to any original zonal structure on the glauconite grains.

The biotite flakes in their unaltered state are about 0 3 x 0 1 mm or smaller On expansion the length of 0 3 mm remains unchanged but the width of 0 1 mm increases to 0 5 mm and occasionally even to 1 0 mm This accounts for the distinctly larger grain size of the glauconite grains as compared with most of the other mineral constituents of the sandstone Prior to the hydration of the biotite and apart from the occasional well rounded coarse grains of quartzite and pellets of mudstone the detrital grains were well sorted The size distribution of the grains appears to agree with that figured by Takahashi (1939 p 511) for typical glauconite sandstones The presence of the occasional well rounded coarse grains is probably due to the fact that they would roll more readily under the action of relatively weak currents or wave movements than angular particles of the same size

A small proportion of the glauconite grains have formed not from biotite but by the impregnation with glauconite of the mudstone pellets that occur sparsely through the rocks The grains so derived can be distinguished even when highly altered because they contain inclusions of small fragments of quartz distinctly smaller than most of the quartz grains in the groundmass (Plate IX fig 8)

ALTERATION OF THE GLAUCONITE

The alteration of the glauconite occurred either prior to or during lithification In some sections (Bore No 5 parish of Colquhoun) normal green and altered brown glauconite with all intermediate stages occur in the same section The altered glauconite grains are sometimes rimmed by a thin margin of greenish glauconite and the shrinkage cracks in the altered glauconite are filled with green or greenish yellow glauconite mud

A small relatively pure sample of the altered glauconite containing some adherent quartz was prepared by crushing the rock from No 10 Government bore parish of Colquhoun with a rolling pin so as not to break the glauconite grains unduly and then separating the glauconite from the bulk of the other minerals in the rock by suspension in bromoform of Specific Gravity 2 85 The glauconite rich product obtained was then screened through a 60 mesh sieve The material retained on the sieve consisted essentially of glauconite grains with a little adhering quartz An analysis of this sample gave the composition shown in Table 1 Analysis No 1 For glauconite to alter to a substance of this composition the silica potash and soda of the original mineral (compare Analyses Nos 3 and 4) must have been replaced extensively by ferric oxide Most observers (Collet and Lee

1905 Cayeux 1916 Milner 1940) agree that glauconite is an unstable mineral which readily alters to limonite or ferruginous clay if exposed to oxidising conditions so that this is a normal change for glauconite to undergo

Such a change could have been brought about by weathering by the action of iron bearing solutions during lithification or during deposition The films of oxide on the occasional coarse rounded grains of quartzite might be regarded as evidence of the passage of oxidizing iron bearing water through the rock but weathering or alteration during lithification seem to be ruled out because the green glauconitic mud that forms the cement of the rock and fills the shrinkage cracks in the altered grains is generally unaltered The association of grains of green and brown glauconite in the same section and the relatively unoxidized state of the pyrite grains in the rock is further evidence supporting this conclusion The fact that there is no concentration of alteration along the margins of shrinkage cracks shows that the alteration took place prior to shrinkage and while the material was still gelatinous

TABLE 1—COMPOSITION OF ALTERED AND NORMAL GLAUCONITE

	1	2	3	4
SiO_2	25 81	27 74	53 61	49 47
Al_2O_3	7 27	13 02	9 56	5 59
Fe_2O_3	47 25	39 93	21 46	19 46
FeO	0 72	1 76	1 58	3 36
MgO	2 14	4 62	2 87	3 96
CaO	2 00	1 19	1 39	0 60
K_2O	2 31	0 95	3 49	8 04
Na_2O	nil	0 62	0 42	0 16
H_2O	11 89	10 85	5 96	8 54
CO_2	tr	—	—	0 56
TiO_2	0 05	—	—	—
MnO	0 05	—	tr	—
P_2O_5	0 35	—	—	1 06
Total	99 84	100 68	100 34	100 80

1 Altered glauconite (with some quartz) from the Miocene glauconite sandstone Bore No 10 parish of Colquhoun Gippsland *Analyst* A B Edwards

2 Decomposed glauconite from recent marine deposits (quoted by Collet and Lee Proc Roy Soc Edin 1905 vol 26 pp 238-278) from Murray and Renard, Deep Sea Deposits Challenger Report 1891)

3 Average of four analyses of recent glauconites collected by the Challenger expedition (Twenhofel Treatise on Sedimentation 1932 p 456)

4 Purified glauconite from Cretaceous of New Jersey (Ibid)

It seems probable, therefore, that this glauconite was altered to limonite or ferruginous clay during its deposition. Glauconite forming in the present oceans is sometimes subject to just such alteration, under conditions that are not yet defined (Collet and Lee, 1905). Comparison of Analysis No. 2 of Table 1 with Analysis No. 1 shows how closely such altered glauconite in deep sea deposits now forming can resemble the altered glauconite of this Miocene sandstone.

Collet and Lee have also shown that a brown ferruginous clay develops as a midstage in the formation of glauconite from pellets of grey clay, the green colour of the glauconite appearing only when potassium is introduced into the ferruginous clay. While this might apply to the brown glauconite developed from the mudstone pellets, it cannot be true for most of the altered glauconite, which was formed from biotite, because Galliher (1935) found no trace of such an intermediate stage in present-day glauconite forming directly from biotite.

PERMEABILITY AND POROSITY.

The permeability of the glauconitic sandstone was first measured by Croll (1939) who used material from the No. 1 Government bore, parish of Colquhoun, the No. 2 bore of the Lakes Entrance Development Co., and the No. 1 Kalimna bore. He obtained an average permeability of 223 millidarcies along the bedding, and of 15 millidarcies across the bedding. Individual measurements ranged from 5 millidarcies to 450 millidarcies. Thyer's unpublished measurements for the No. 10 bore indicate a lower permeability, with no consistent difference in directions parallel to and transverse to the bedding.

The appearance of the glauconitic sandstone in thin section throws little light on the variable permeability, and fails to account for the unusally high porosity of the dried rock. A piece of the air-dried core of No. 11 bore, parish of Colquhoun, was ground to a block measuring 7·5 x 6·0 x 6·0 cm. This was immersed in distilled water. Innumerable minute bubbles developed on the surface of the block, and showed only a very slight enlargement in size, until they escaped from the surface after one or more days, without other bubbles forming in their place. From three or four points, however, strong persistent streams of minute bubbles issued, several hundred bubbles being emitted per minute by each stream. These streams of bubbles continued for about two and a half hours. The bubbles from two such streams were trapped in inverted test tubes filled with water, from which it was found that the volumes of air emitted by the bubble streams amounted to 8 c.c. for one stream and nearly 10 c.c. for the other.

This feature of the emission of persistent streams of bubbles at one or two points was noted in practically all the specimens immersed in xylol-canada balsam solutions. In some instances, air from connected channelways issued at two points on the same specimen, and filling of the pores with solution led to the sudden cessation of one stream of bubbles, with a simultaneous increased emission in the other stream. This, coupled with the practical absence of bubble emission over large areas of the specimens, indicates that the larger open spaces in the rock tend to be localized, and so explains the great variability in permeability noted by Croll and Thyer. It was also noted, in the case of the large block of rock referred to above, that the bubble streams issued from faces at right angles to the bedding of the rock, rather than from faces parallel to the bedding, suggesting that, as Croll found, there may in some specimens be a somewhat greater permeability parallel to the bedding than across it.

The absorption ratio of this block of rock, after immersion for seven days, followed by drying for six hours at 105°C., and for a further three days in a sulphuric acid dessicator at room temperatures, was 17·8 per cent. Repetition gave a practically identical result. The specific gravity of the powdered rock from which the block was cut was 1·8, so that the apparent porosity of the block was approximately 32 per cent., which is of the same order as Thyer's more accurate measurements.

The absorption ratios measured in the same way on air-dried specimens from three other bore cores, namely No. 5 bore (1,238-43 feet), No. 8 bore (1,055 feet), and No. 10 bore (1,270-72 feet) were 10·5 per cent., 16·5 per cent., and 17·2 per cent. respectively, corresponding to apparent porosities of about 18 per cent., 29 per cent., and 31 per cent.

These high absorption ratios may be a measure of the pore space of the rock, or they may represent the capacity of the glauconitic mud cement to absorb water. If they measure the pore space of the rock, then since there are no obvious cavities or open spaces of this volume present, then such pore space can be accounted for only as due either to incomplete compaction allowing the existence of submicroscopic openings along the grain boundaries and in the glauconitic mud cement, or to air-drying of the rock inducing such openings in the cement.

To test this, specimens of the glauconitic sandstone were impregnated with a bright red xylol-balsam solution, so that the distribution of the balsam absorbed by the rock could be traced in thin section. The balsam was intensely coloured by means of an oil-soluble red dye, which is manufactured by British Drug

Houses and is soluble in xylol On evaporating out the xylol from the xylol balsam solution on a hot plate and heating the balsam until it set hard the balsam retained the dye though remaining perfectly transparent and the colour remained fast In thin sections the coloured balsam appeared pink

A series of sections were prepared from air dried material imgregnated with this red balsam from the cores of the No 4 No 6 No 8 and No 10 bores The thin sections revealed only a few actual fractures grain boundaries or natural open spaces filled with pink balsam and more often than not the shrinkage cracks in the grains of altered glauconite remained unfilled The cement of glauconitic mud however was changed in colour from green or yellowish green to a pinkish brown indicating that the dyed xylol balsam solution had penetrated it more or less uniformly presumably along submicroscopic openings The pinkish colour was not due to reaction with the glauconitic mud cement because over a period of about seven days the glauconitic mud cement slowly resumed its normal greenish colour possibly as a result of slow oxidation of the dye stuff or of base exchange between it and the dye stuff It is concluded from this that the glauconitic mud forming the natural cement of the rock is highly porous in its air dried state the pore being chiefly capilliary openings with diameters between 0 001 mm and 0 0002 mm The natural cement commonly constitutes 50 per cent or more of the rock so that if it were highly porous such openings could account for much or all of the measured porosity

It seems highly doubtful however that this measured porosity is the true porosity of the rock in its natural state because even air drying of the rock might cause a shrinkage of the natural cement and increase the porosity of the rock considerably

Conclusion.

Glauconite can form from a variety of substances provided that they become gelatinous through hydration (Takahashi 1939 pp 506 512) Such substances include faecal pellets clay colloidal and opaline silica sponge spicules fragments of volcanic glass and minerals such as felspars pyroxenes and micas Which of these substances will be the dominant source in any one locality will depend partly on the mineral composition of the rocks from which the sedimentary materials are derived and partly upon their relative susceptibility to hydration and gelatinization other factors being equal

Thus in areas like that under consideration where the sedimentary material was derived largely from granitic rocks the substances most susceptible to glauconitization that will be present in abundance are biotite and felspar The observations of Galliher (1935) and those described above show that in such circumstances biotite becomes hydrated and gelatinous much more readily than the associated felspars so that the biotite tends to be altered to glauconite while the felspar remains fresh and unaltered

The alteration of glauconite to ferruginous clay or limonite follows the same general course whether the alteration takes place during deposition during diagenesis or subsequently as a result of weathering Altered glauconite is not therefore of itself sufficient evidence of a disconformity in a sedimentary series

It is also clear that the appearance of a rock in thin section is not always a reliable guide as to its porosity and that special techniques such as impregnating the rock with coloured media are necessary to determine the nature of the open spaces Moreover in dealing with rocks which contain a considerable proportion of clays or clay like substances any drying of the rock may cause considerable shrinkage of such substances so that porosity measurements on such dried rock will not be a measure of the porosity of the rock in its natural state

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Description of Plate.

PLATE IX.

FIG 1—Oval grain of altered glauconite which has shrunk away from the enclosing matrix The protuberances and indentations on the edge of the altered glauconite match similar fractures on the edge of the matrix, indicating that the void has not been caused by the grinding of the rock section Below it is a sub-angular grain of altered glauconite. Ordinary light. × 100

FIG 2—Oval and bean shaped grains of altered glauconite showing pattern of shrinkage cracks filled by unaltered glauconite material similar to that forming the cement of the matrix of the rock Ordinary light. × 100

FIG 3—Oval grain of altered glauconite with internal shrinkage cracks. × 100

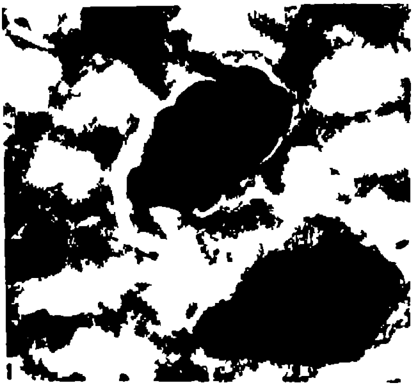
FIG 4—Curved grain of expanded biotite unequally swollen in the direction at right-angles to the cleavage planes Ordinary light × 100

FIG 5—Fan shaped grain of expanded biotite Ordinary light × 100

FIG 6—Grain of partly altered glauconite showing traces of cleavage planes of original biotite × 100

FIG 7—Oval pellet of mudstone containing minute inclusions of quartz × 75

FIG. 8—Part of oval grain of altered glauconite on right with enclosed grain of quartz smaller than quartz in matrix and irregular flake of expanded biotite partly replaced along cleavages by green glauconite × 100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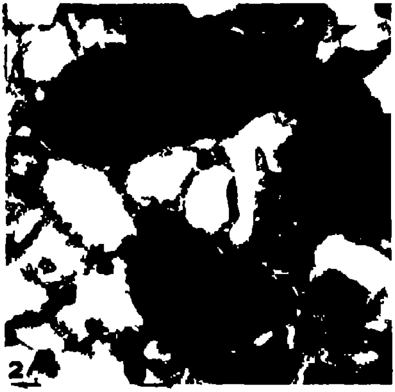
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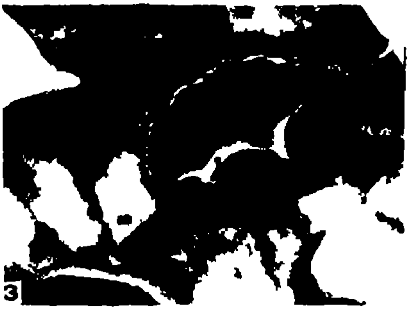
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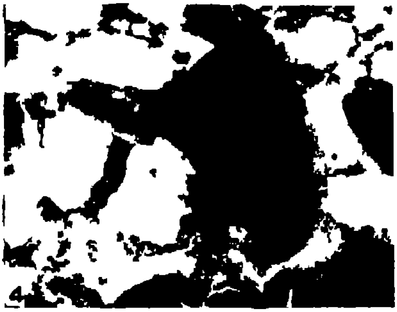
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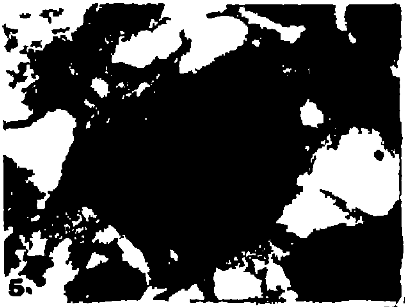
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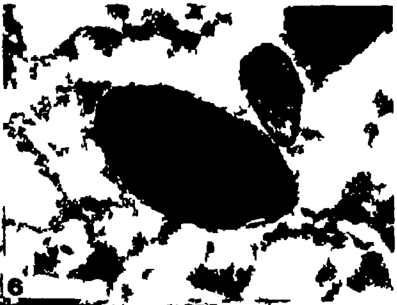
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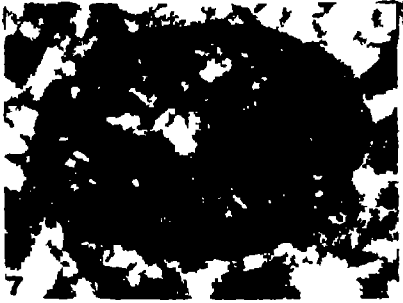
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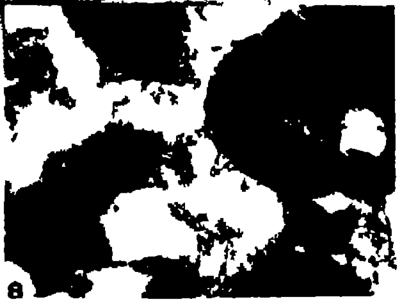
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Miller, E. Studley, 220 Kooyong-road, Toorak, S.E.2	1921
Miller, Leo F., "Moonga," Power-avenue, Malvern, S.E.4 ..	1920
Millikan, C. R., M.Agr.Sc., Plant Research Laboratory, Swan-street, Burnley, E.1	1941
Montgomery, J. N., c/o A'asian Petroleum Co. Pty. Ltd., 37 Queen-street, C.1.	1945
Moore, K. Byron, 11 Mona-place, South Yarra, S.E.1	1945
Morrison, P. Crosbie, M.Sc., 44-74 Flinders-street, C.1	1938
Nicholas, Geo. R., 48 Lansell-road, Toorak, S.E.2	1934
Olsen, C. O., B.A., Dip. Ed., 46 Clendon-road, Toorak, S.E.2 ..	1945
Orr, Dr. R. Graeme, M.A., B.Ch., 11 Maple-grove, Toorak, S.E.2 ..	1935
Orr, Dr. W. F., 8 Collins-street, Melbourne, C.1	1932
Parr, W. J., 17 Bokhara-road, Caulfield, S.E.8	1927
Patton, R. T., D.Sc., M.F., Hartley-avenue, Caulfield, S.E.8 ..	1922
Pescott, R. T. M., National Museum, Melbourne, C.1	1944
Piesse, E. L., 43 Sackville-street, Kew, E.4	1921

Pittman, H. A. J., B.A., B.Sc.Agr. (Hons.), Dip.Ed., Plant Research Laboratory, Swan-street, Burnley, E.1	1942
Priestley, R. E., M.A., D.Sc., University, Birmingham	1935
Quayle, E. T., B.A., 27 Collins-street, Essendon, W.5	1920
Reid, J. S., 498 Punt-road, South Yarra, S.E.1	1924
Richardson, A. E. V., M.A., D.Sc., C.M G., Council for Scientific and Industrial Research, 314 Albert-street, East Melbourne, C.2	1938
Rivett, Sir David, K.C.M.G., M.A., D.Sc., Council for Scientific and Industrial Research, 314 Albert-street, East Melbourne, C.2	1911
Rogers, J. Stanley, B.A., D.Sc., University, Carlton, N 3	1924
Rose, F. G. G., Central Weather Bureau, Box 1289k, G P.O., Melbourne, C.1	1944
Sewell, Sir Sidney V., 12 Collins-street, C.1	1936
Assoc.-Prof. **Singleton**, F. A., D.Sc., University, Carlton, N.3	1917
Smith, Dr. Hubert R., 59 Collins-street, C.1.	1945
Stillwell, F. L., D.Sc., 44 Elphin-grove, Hawthorn, E.2	1910
Stokes, Dr. H. Lawrence, 232 Kooyong-road, Toorak, S.E.2	1945
Stokes, Russell N., 2 Torresdale-road, Toorak, S.E.2	1945
Sullivan, W., 326 Exhibition-street, Melbourne, C.1	1943
Sunderland, Professor S., D.Sc, M.B, B.S., University, Carlton, N.3	1945
Tattam, Dr. C .M., Ph.D, D.Sc., D.I.C., University, N.3	1945
Thomas, Dr. D. J., M.D., 81 Collins-street, Melbourne, C.1	1924
Tiegs, Assoc. Prof. O. W., D.Sc., F.R.S., University, Carlton, N.3	1925
Turner, Professor J. S., M.A., Ph.D., University, Carlton, N.3	1938
Vail, Col. L. E., 485 Bourke-street, Melbourne, C.1	1939
Wadham, Prof. S. M., M.A., Agr. Dip., University, Carlton, N.3	1932
Weigall, Dr. Gerald, 34 Avoca-street, South Yarra, S.E.1	1945
Wettenhall, Dr. Roland R., "Aberfeldie," 557 Toorak-road, S.E.2	1938
White, Dr. A. E. Rowden, 14 Parliament-place, Melbourne, C.2	1938
Withers, R. B., M.Sc., Dip. Ed. Technical School, Brunswick, N.10	1926
Woodruff, Professor H. A., M.R.C.S., L.R.C P., M.R.C.V.S., 84 Fellows-street, Kew, E.4	1913
Wright, Prof. R. D., D.Sc., M.B., M.S., F.R.A.C.S, F R.A.C.P., University, Carlton, N.3	1941

COUNTRY MEMBERS.

Adams, H. G., "Danedite," Werribee, Vic.	1945
Blackburn, Maurice, M.Sc., Fisheries Section, C.S.I.R., Cronulla, N.S.W.	1936
Burston, Gerald, "Koorana," Euroa, Vic.	1945
Caddy, Dr. Arnold, "Chandpara," Tylden, Vic.	1924
Caldwell, J. J., Geological Survey Office, Bendigo, Vic.	1930
Crawford, W., Gisborne, Vic.	1920
Currie, Mrs. Ian, Seven Oaks, Euroa	1941
Felstead, Dr. J. G. R., Box 30, Horsham	1945

Glaessner M F Ph D Australasian Petroleum Co Pty Ltd 37 Queen street Melbourne C 1	1939
Gloe C State Rivers and Water Supply Dept Eildon Weir	1944
Harris W J I A D Sc Box 34 Warragul Vic	1914
Hill Dr Dorothy M Sc Ph D Geology Dept University of Brisbane	1939
Hope G B B M E Carrical Hermitage road Newtown Geelong Vic	1918
Jenkin J J 35 Marley street Sale	1945
Knight J L B Sc State Coal Mines Wonthaggi	1944
Lawrence A O B Sc Dip For 509 Ligar street Ballarat	1931
Mackenzie H P Engr Commr R N (Ret) Trawalla Vic	1924
Mann S F Caramut Vic	1922
Payne T F Neville Woodburn Kilmore Vic	1945
Quayle D S 33 Gent street Ballarat	1939
Thomas D E c/o Geological Survey Mines Dept Hobart	1929
Trebilcock Captain R L M C Wellington street Kerang Vic	1921
Weatherly W D F C B A Woolongoon Mortlake Vic	1945
White R A B Sc School of Mines Bendigo Vic	1918
Yates H School of Mines Ballarat Vic	1943

ASSOCIATES

Aitken Miss Y M Agr Sc School of Agriculture University Carlton N 3	1936
Alderman A R M Sc Ph D F G S Box 4331 G P O Melbourne C 1	1942
Bage Miss F M Sc O B E Womens College Kangaroo Point Brisbane Qld	1906
Baker G M Sc Geology Department University N 3	1935
Bottoms E A 68 Robinsons road Hawthorn E 2	1943
Brazenor C W National Museum Russell street Melbourne C 1	1931
Broadhurst F M Sc 457 St Kilda road Melbourne S C 2	1930
Butcher A D M Sc Fisheries & Game Dept 605 Flinders street C 1	1936
Butler L S G No 3 Los Angeles Court St Kilda S 2	1929
Campbell J D B Sc B M E 1327 Burke road Kew	1932
Canavan F B Sc c/o Broken Hill Pty Ltd, 422 Little Collins-street Melbourne	1936
Carter A A C Fairholm Threadneedle street Balwyn, E 8	1927
Chapman W D Major M C E Hellas Stawell street Kew, E 4	1927
Chapple Rev E H The Manse Warrigal road Oakleigh, S E 12	1919
Clinton H F Department of Agriculture Public Offices C 2	1920
Cochrane G W B Sc Queens College Carlton N 3	1945
Collins A C 3 Lawrence street Newtown Geelong	1928
Colliver F S 14 McCarron parade Essendon W 5	1933
Condon M A B Sc c/o Melbourne and Metropolitan Board of Works Melbourne	1937
Cook G A M Sc B M E 58 Kooyongkoot road Hawthorn E 2	1919
Cookson Miss I C D Sc 154 Power street, Hawthorn, E 2	1916

Coulson, A., M.Sc., 66 Spencer-street, Essendon, W 5	1929
Coulson, A. L., D.Sc., D.I.C., F.G.S., 324 Cotham-road, Kew, E.4	1919
Cowen, Miss Margot E. H., B.Agr.Sc, 2 Leaburn-avenue, S E 7	1936
Crespin, Miss I., B.A., Mineral Resources Survey, Census Building, City, Canberra, A C.T.	1919
Croll, I. C. H., M Sc, 53 The Boulevard, Hawthorn, E 2	1934
Croll, R. D., B.Agr Sc., 18 Russell-street, Camberwell, E 6	1940
Dadswell, Mrs. Inez W, M.Sc., University, N 3	1939
Deane, Cedric, "Rothley," Sorrett-avenue, Malvern, S E 4	1923
Dewhurst, Miss Irene, B.Sc, 2 Pine-grove, McKinnon, S E 14	1936
Dickinson, Miss Jill, B Sc, State Laboratories Treasury Gardens	1944
Down, Mrs. Mary R, B Agr.Sc., 18 Merton-street, Ivanhoe	1942
Edwards, G. R., B.Sc, Powell-street, St Arnaud	1937
Elford, F. G., B.Sc., B.Ed, 76 New-street, Brighton, S 5	1929
Elford, H. S., B.E, c/o Tait Publishing Co, 349 Collins street, Melbourne, C.1	1934
Fawcett, Miss Stella G. M., M Sc., Box 54, P O. Omeo	1937
Ferguson, W. H., 37 Brinsley road, E Camberwell, E 6	1894
Fisher, Miss E. E., M Sc., Ph D. 1 Balwyn-road, Canterbury, E 7	1930
Forster, H. C, B Agr Sc, Ph D, 6 Glendene-avenue, Kew, E 4	1938
Frostick, A. C., 9 Pentland-street, N Williamstown, W 16	1933
Gabriel, C J., 293 Victoria-street, Abbotsford, C 1	1922
Gaskin, A. J., M.Sc., 6 Olive-street, E. Malvern, S E 5	1941
Gillespie, J. M., M.Sc., 22A Mercer-road, Malvern, S E 3	1941
Gladwell, R A., 79 Cochrane-street, Elsternwick, S 4	1938
Gordon, Alan, B.Sc, c/o C.S I.R., Yarra Bank-road, South Melbourne, S C.4	1938
Goudie, A. G., B.Agr.Sc, Department of Agriculture, Melbourne	1941
Grieve, Brian J., M.Sc, Ph.D, D I C., Botany School, University N.3	1929
Gunson, Miss Mary, B Sc, Zoology Dept, University, N 3	1944
Hanks, W., 7 Lake-grove, Coburg, N 14	1930
Hardy, A. D, 24 Studley-avenue, Kew, E 4	1903
Hauser, H. B., M.Sc., Geology School, University, Carlton, N 3	1919
Head, W. C. E., Campbell-street, Nhill	1931
Heysen, Mrs. D., P.O. Box 10, Kalangadoo, South Australia	1935
Holland, R. A., 526 Toorak-road, Toorak, S E 2	1931
Holmes, W. M, M A., B.Sc., 1 Balmoral avenue, Kew, E 4	1913
Honman, C. S., B.M.E., Melbourne Technical College, 134 Latrobe-street, C.1	1934
Hutchinson, R. C., B Sc, Dept. of Agriculture, Rabaul	1939
Jack, A. K, M.Sc., 49 Aroona-road, Caulfield, S E 7	1913
Jacobson, R., M.Sc., 41 Thanet-street, Malvern, S.E 4	1937
Jessep, A. W., B.Sc., M.Ag.Sc, Botanical Gardens Sth Yarra, S.E.1	1927
Jona, J. Leon, M.D., M S, D Sc, Lister House, 61 Collins-street, Melbourne, C.1	1914
Kenny, J. P. L., B.C.E., Mines Department, Public Offices, C.2	1942
Kilvington, T., M.Sc., Physiology Department, University, N.3	1938

Langham, Miss Beryl, B.Sc., 8 Myrtle-road, Hampton, S.7 .. 1945
McCance, D., M.Sc., 144 Gatehouse-street, Parkville, N.2 1931
McLennan, Assoc. Prof. Ethel, D.Sc., University, Carlton, N.3 .. 1915
Macpherson, Miss J. Hope, National Museum, Melbourne . 1940
Manning, N., 16 Fairmont-avenue, Camberwell, E.6 1940
Melhuish, T. D'A., M.Sc., c/o Elliots & Aust. Drug Pty. Ltd., Terry-street, Rozelle, N.S.W. 1919
Morris, P. F., National Herbarium, South Yarra, S.E.1 1922
Moy, A. F., Melbourne Boys High School, Prospect Hill-road, Canterbury, E.7. 1943
Mushin, Mrs. Rose, 150 Garton-street, North Carlton, N.4 1940
Newman, B W., B.Sc., Meteorological Bureau, Sydney 1927
Nye, E. E., College of Pharmacy, 360 Swanston-street, Melbourne, C.1 1932
Oke, C., 34 Bourke-street, Melbourne, C.1 1922
Osborne, N., 35 Dorrington-avenue, Glen Iris, S.E.6 1930
Pinches, Mrs. M, 8 Thomas-street, Brunswick, N.10 1943
Prentice, H. J., B.Sc, Higher Elementary School, Wodonga .. 1936
Pretty, R. B., M.Sc., Technical School, Wonthaggi, Vic. 1922
Raff, Miss J. W., M.Sc., F.R.E.S., University, Carlton, N.3 .. 1910
Rayment, Tarlton, Bath-street, Sandringham, S.8 1929
Richardson, Sidney C, 16 Brewster-street, Essendon, W.5 1923
Samson, H. R., B.Sc., 34 Park-street, Parkville, N.2 1945
Sayce, E L., B.Sc., A Inst P., Research Laboratories, Maribyrnong, W.3 1924
Scott, T. R, M.Sc., B.Ed., 27 Currajong-avenue, Camberwell, E.6 .. 1934
Shaw, Dr. C. Gordon, 57 Clendon-road, Toorak, S E.2 1931
Sherrard, Mrs. H. M., M.Sc., 43 Robertson-road, Centennial Park, N.S.W. 1918
Singleton, O. P., 126 Anderson-street, South Yarra, S E.1 1943
Stach, L. W., M.Sc., 250 Riversdale-road, Hawthorn, E.3 .. 1932
Stubbs, G. C., Plant Laboratory, Burnley, E.1 1943
Thomas, G. A., B.Sc., National Museum, Melbourne 1944
Thomas, L. A., B Sc., c/o Council for Scientific and Industrial Research, Stanthorpe, Queensland 1930
Trüdinger, W., 27 Gerald-street, Murrumbeena, S.E.9 1918
Tubb, J. A., M.Sc., Fisheries Section, C.S.I.R., Cronulla, N.S.W. .. 1936
Vasey, A J., B.Agr.Sc., Animal Health Laboratory, Parkville, N.3 1937
Vasey, G. H., B.C.E., University, Carlton, N.3 1936
Wade, G. C., B.Agr.Sc., Plant Research Laboratory. Swan-street, Burnley, E.1 1941
Whincup, Mrs. Sylvia, B Sc., Kerang 1942
Wilcock, A. A., B.Sc., B.Ed., 21 Park-road, Maryborough 1934
Wilson, F. E., F.E.S., 22 Ferncroft-avenue, E. Malvern, S.E.5 .. 1921
Wood, Prof. G. L, M.A., Litt. D., University, Carlton, N.3 .. 1933
Woodburn, Mrs. Fenton, 21 Bayview-crescent, Black Rock, S.9 .. 1930
Wunderly, J., D.D.Sc. (Melb.), 7 Victoria-road, Camberwell, E.6 .. 1937

Royal Society of Victoria.

ANNUAL REPORT OF THE COUNCIL

FOR THE YEAR 1944

The Council presents to members of the Society the Annual Report and Statement of Receipts and Expenditure for the year 1944. The following meetings of the Society were held:

March 9: Annual Meeting. The following office-bearers were elected: President, Mr. W. Baragwanath; Vice-Presidents, Major D. A. Casey, Captain J. K. Davis; Honorary Treasurer, Mr. W. J. Parr; Honorary Librarian, Mr. F. A. Cudmore; Honorary Secretary, Dr. F. L. Stillwell; Members of Council, Professor E. W. Skeats, Professor S. M. Wadham, Professor R. D. Wright, Dr. R. T. Patton, Mr. D. J. Mahony, Mr. Crosbie Morrison.

The following members of Council continued in office: Professor W. A. Osborne, Professor H. S. Summers, Professor J. S. Turner, Dr. J. M. Baldwin, Mr. J. S. Rogers, Associate-Professor O. W. Tiegs.

The Annual Report and the Financial Statement for 1943 were read and adopted.

At the close of the Annual Meeting an Ordinary Meeting was held. Lecture: "Flax and Flax Production," by Dr. I. F Phipps.

April 13: Lecture: "The Electron Microscope," by Dr. J. S. Hosking.

May 11: Lecture: "The Road to Darwin with the Army Education Services in Northern Australia," by P. Crosbie Morrison.

June 15: Lecture: "The Meteorological Conditions of Gliding," by Dr. F. Loewe.

July 13: Papers: "Classification of Victorian Plant Communities," by Dr. R. T. Patton. "The Stratigraphical Range and Habitat of the Diprotodontidae in South-East Australia," by R. A. Keble. "Note on Some Buried Valleys along the South Gippsland Coast," by Dr. A. B. Edwards. "Geology of Phillip Island," by Dr. A. B. Edwards.

August 10: Lecture: "Some Borderlands of Microbiology, Biochemistry and Genetics," by Dr. F. M. Burnet.

September 14: Lecture: "Sheep and Wool: Recent Research and Prospective Developments," by Professor A. F. Barker.

October 12: Lecture: "The Problem of the Origin of Insects," by Associate-Professor O. W. Tiegs.

November 9 Papers "Note on the Age and Palaeogeography of the Brown Coal Deposits of Gippsland, Victoria," by Irene Crespin "Australian Ambrosia Fungi," by Mrs Shirley Webb Lecture The Leigh Creek Coalfield, by Dr A B Edwards

December 14 Papers "Botrytis Corm Rot of the Gladiolus —Its Cause and Control,' by G C Wade "A Glauconitic Sandstone from the Tertiary of East Gippsland," by Dr A B Edwards The Chonetidae of the Palaeozoic Rocks of Victoria," by Rev E D Gill A Commentary on a Recent Classification of the Gippsland Tertiary," by Dr F A Singleton "Tertiary (Janjukian) Shelly Faunules from near Princetown, Victoria," by Dr F A Singleton and Owen P Singleton

The Society s Hall was still required by the Army Hiring Department under the National Security Regulations for Defence purposes, but satisfactory arrangements continued for its use by the Society for the monthly meetings

Reciprocal arrangements have been made with the Royal Societies in other States whereby members visiting another State, may attend meetings and use the library of the Royal Society in that State on production of a letter from the Secretary of this Society The privileges are available for three months, and may be extended at the discretion of the Council of the local Society

During the year two members, two country members and three associate members were elected

The Council deeply regrets the loss by death of three life members, one member, one country member and two associate members

Thomas Ranken Lyle Kt M A , D Sc F R S Emeritus Professor of Natural Philosophy of the University of Melbourne, was born in 1860 in Coleraine, Northern Ireland, and educated at the Coleraine Academic Institute and Trinity College, Dublin He graduated with high academic distinctions which were combined with athletic prowess His first post was lecturer in mathematics at the Catholic College Dublin and he was a member of the Irish International Rugby Football teams of 1885-7 In 1889, he was appointed Professor of Natural Philosophy in the University of Melbourne holding the chair until his retirement in 1915 In 1905 he was awarded the D Sc of Dublin University and, in 1912, he was elected F R S After relinquishing his Chair he was associated with H J Grayson at the University of Melbourne in the production of diffraction gratings, and, after Grayson s death, purchased the machine from Grayson's estate Just before his death he donated this machine to the National Standards Laboratory of Australia Lyle carried a load of important public responsibilities, being rewarded with a knighthood in 1922 He was the first Chairman of the State Electricity Commission and afterwards continued as a member He was chairman of the Board of Visitors at the Melbourne Observatory from 1903, a member and Vice-President of the Council of Education He was a director of the Metropolitan Gas Co., a member of the Federal Munitions Committee set up during the 1914-18 war, a chairman of the Industries Exemption Committee and first chairman of the Standards Association of Australia. Lyle's published contributions to science lie mainly in the domain of electrical circuit theory. He was the first to give a complete theory of the simple alternator, and he was among the first in Australia to take X-ray photographs, using tubes made with his own hands. He contributed articles on related subjects to the Proceedings of this Society in 1904-5. He was elected a member of the Society in 1889 and an honorary life-member in 1938. He died on March 31 at the age of eighty-three.

Ambrose Pratt was born at Forbes, N.S.W., in 1874, and educated at the Sydney Grammar School and Sydney University, graduating in law in 1896. Within a few years he retired from the legal profession and went to England, published several novels and entered the field of journalism. Returning to Australia in 1904, he became a leader writer on the "Age." In 1915 he became editor and part proprietor of the Australian Industrial and Mining Standard, retiring from journalism in 1927. He then became company director to several tin dredging companies in Malaya and Thailand. Apart from his newspaper work, he wrote about 30 novels, as well as several zoological, economic and historical works. His interests were wide and he was for many years President of the Royal Zoological and Acclimatisation Society of Victoria, a member of the committee of the library Association and a vice-president of the League of Youth Movement. He was also a member of the Board of Management of Mount Royal Hospital and Queen's Memorial Hospital. He was elected a member of this Society in 1918 and became a life member in 1933. He died on September 13 at the age of 70 years.

Daniel James Mahony, M.Sc., was born in 1878 at Melbourne, and graduated as a bachelor of science at the University of Melbourne in 1904. In 1906 he joined the Geological Survey of Victoria as petrologist. In 1912 he was locum tenens for Sir Douglas Mawson at the Adelaide University during the Australasian Antarctic Expedition. He served with the Royal Artillery in the war of 1914-1918. In 1931 he was transferred from the Geological Survey of Victoria to the post of Director of the National Museum. In this capacity he introduced the dioramas and staged a fitting setting of the famous ethnological collection. In doing so, Mr. Mahony contributed generously from his own pocket and secured substantial donations from some of his friends. He helped to form the Galleries and Museums Association of Australia, of which he was the first chairman. He was a chairman of the scientific committee of the Zoological Board of Victoria. He joined this Society in 1901, and served as a member of Council from 1931 till his death, being President 1939-1940. He contributed two papers on Tertiary Volcanic Rocks to the Proceedings of the Society. He died on September 28 shortly after his retirement from the Museum.

Gilbert Rigg was born in England in 1873. He commenced his association with zinc production in 1906, when he was appointed chief of the research department of the New Jersey Zinc Co., U.S.A., and in the last five years of his engagement he also held the position of sales engineer. In 1916, he came to Australia as metallurgical engineer to the Broken Hill Associated Smelters Pty. Ltd., and, at the same time, he became consulting metallurgical engineer to the Electrolytic Zinc Co. of Australasia Ltd. In 1924, jointly with Herbert Gepp, he was awarded the Gold Medal of the Institution of Mining and Metallurgy, London, in recognition of joint and individual achievements in the development of the electrolytic process for the production of zinc, and in the treatment of complex sulphide ores in Australia. After 1926, he retired from active professional life though still retaining his connection with the Broken Hill Associated Smelters as consultant. He then devoted himself more and more to his own private researches, maintaining a keen interest in those scientific developments which particularly interested him. He was elected a member of this Society in 1931. He died on September 2.

Herbert Montgomerie Standish Cox, of Wombat Park, Daylesford, pastoralist, died on March 14, 1944, aged 85. He was born at Rawdon Station, Rylston, N S.W., and was a famous horseman in his younger days. He was a grandson of Captain William Cox who organised and carried out the construction of the first road from Sydney across the Blue Mountains, which was completed in 1815, eighteen months after it was begun. He was elected a country member of this Society in 1931.

John George Easton joined the Mines Department in 1897, and first served as assistant on geological surveys in the Snowy River, the Apollo Bay-Forrest and the Baw Baw-Aberfeldy districts and on a detailed survey of the Berringa mines. In 1904, he was appointed to take charge of a survey of the Myrtleford auriferous belt, which was subsequently extended to include the Buckland River, Buffalo Creek, Stanley and Twist's Creek areas. He was next engaged in mapping large areas in the northern portion of Benambra and, from 1923-35, with his headquarters at Bairnsdale, he conducted a geological and topographical survey of considerably more than 500 square miles of Eastern Gippsland. He retired in 1942, but was immediately engaged by the Commonwealth Government to supervise the boring for bauxite in Gippsland. In 1943, he was re-employed by the Mines Department as curator of the Geological Museum, and held this post until his death on August 9, 1944. He was elected an associate member of the Society in 1913, and contributed a paper as joint author with Dr. A. B. Edwards on the "Igneous Rocks of North-Eastern Benambra" to the Proceedings of this Society.

John Cuthbert Traill was born at Geelong in 1864 and educated at Geelong Grammar School and Melbourne University.

He was one of the earliest students of Ormond College and graduated B.A., B.C.E., in 1888. He then joined the staff of Huddart Parker Ltd., of which his father was one of the founders. He was at one time manager of the Geelong office and was transferred later to Melbourne. He maintained a wide interest in cultural matters and was president of the Old Ormond Students' Association in 1923-4. He was elected an associate member of this Society in 1903. He died on August 21 at the age of eighty.

The attendances at the Council meetings were as follows: Mr. Baragwanath, 10; Mr. Morrison, 10; Mr. Parr, 10; Dr. Patton, 10; Dr. Baldwin, 9; Mr. Cudmore, 9; Professor Skeats, 8; Dr. Stillwell, 8; Associate Professor Tiegs, 8; Captain Davis, 7; Professor Summers, 7; Mr. Rogers, 5; Professor Turner, 5; Professor Wadham, 5; Mr. Mahony, 4; Professor Osborne, 0; Professor Wright, 0. Major D. A. Casey was granted leave of absence for military duties.

During the year, 831 volumes and parts were added to the library. Many of the overseas exchanges are temporarily suspended on account of the war. Owing to man-power difficulties arising from the war, the Hon. Librarian has carried on without the help of an assistant librarian. Members are asked to co-operate by returning borrowed books within the specified time limit of three months. The value of the library has proved itself in the war effort. Books have been lent to Australian, American and Dutch Forces, also to departments and firms on war work, while the Society is co-operating in the compilation, by the Allied Geographical Section, of an Annotated Bibliography of the Southwest Pacific and Adjacent Areas.

Volume 56, Part 1, of the Proceedings of the Society was issued on August 1. The publication of this volume was assisted by a credit of £100 made available at the Government Printing Office by the State Government, and by grants from the University Publications Fund, towards the cost of publishing papers from the Science Departments of the University of Melbourne.

HONORARY TREASURER'S REPORT.

The financial statement shows a credit balance of £371/10/9 at 31st December, 1944, as against £194/12/2 at the end of the previous year. This balance does not, however, represent the true position, as, because of delays in printing, the second part of Volume 56 of the Proceedings was not published during the year, and this expenditure, estimated at £230, has yet to be met.

Subscriptions have been well maintained, but the falling off in the total general receipts other than rents has continued. Rents have increased as a result of the temporary occupation of part of the Hall by the R.A.A.F. Without the receipts from this source the financial position of the Society would be deteriorating because of the greatly increased cost of printing the Proceedings.

Financial Statement for Year ending December 31st, 1944

RECEIPTS

Balance in Bank at 1/1/44		£194 12 2
Subscriptions—		
Members	£107 2 0	
Associate Members	68 4 6	
Country Members	11 11 0	
Arrears paid up	59 6 6	
Advance Subscriptions	4 14 6	
		250 18 6
Rents—		
Com wealth Government	£100 0 0	
R A A F	156 0 0	
Field Naturalists Club	16 0 0	
Microscopical Society	9 0 0	
		281 0 0
Sale of Publications		19 0 10
Interest on Bonds		14 5 0
Grants and Donations—		
Government of Vict.	£100 0 0	
Univ of Melbourne	40 0 0	
		140 0 0
Surplus Cash		6
		£899 17 0

EXPENDITURE

Printing—		
Vol. 56, part 1	£204 12 6	
General	28 16 10	
		£233 9 4
Salaries—		
Asst Secretary	24 0 0	
Assistant Editor	10 0 0	
Hallkeeper	12 0 0	
Gardener	26 7 6	
		72 7 6
Light, Water Gas		10 10 6
Telephone		11 2 3
Rates		14 6 8
Insurance		5 1 3
Petty Cash		10 16 2
Postage		12 18 4
Repairs and Replacements		34 17 3
Meetings		6 18 3
Library		4 15 4
War Savings Certificates		100 0 0
Fire Extinguishers		8 16 5
Sundries		2 7 0
Balance in Bank at 31/12/44		371 10 9
		£899 17 0

W J PARR, *Hon Treasurer*

Audited and found correct

31st January 1945

WILFRID N KERNOT } *Hon*
F M CHERRY } *Auditors.*

SPECIAL FUNDS.

HALL FUND.

	£	s.	d.		£	s.	d.
Balance at 1/1/44	£61	3	4	Balance at 31/12/44	£62	7	9
Interest to 31/5/44	1	4	5				
	£62	7	9		£62	7	9

LIFE MEMBERSHIP FUND.

	£	s.	d.		£	s.	d.
Balance at 1/1/44	£94	9	2	Balance at 31/12/44	£96	4	10
Interest to 31/5/44	1	15	8				
	£96	4	10		£96	4	10

HOWITT MEMORIAL FUND.

	£	s.	d.		£	s.	d.
Balance at 1/1/44	£88	2	0	Balance at 31/12/44	£93	14	2
Interest on Bond	3	17	6				
Savings Bank Interest to 31/5/44 ...	1	14	8				
	£93	14	2		£93	14	2

SPECIAL FUNDS (continued)

T. S. HALL MEMORIAL FUND.

Balance at 1/1/44	£69	18	7	Balance at 31/12/44	£71	6	2
Interest to 31/5/44	1	7	7				
	£71	6	2		£71	6	2

Accounts and Pass-books relating to each of the above Funds have been severally examined and found correct, and the Bank certificate of possession of Bonds amounting to Five Hundred Pounds (£500) and War Savings Certificates to the face value of One Hundred and Twentyfive Pounds (£125) has also been inspected.

W. J. PARR, *Hon. Treasurer.*

31st January, 1945

WILFRID N. KERNOT } *Hon.*
T. M. CHERRY } *Auditors.*

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J. J. GOURLEY,
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PROCEEDINGS

OF THE

Royal Society of Victoria.

VOL. LVIII (NEW SERIES)

PARTS I AND II

ISSUED 25th JUNE 1947

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MEMORANDUM FOR AUTHORS

Authors are particularly requested to note the following instructions before submitting papers for publication.

1. Papers must be in a form suitable for publication and complete when communicated to the Society, and should be as concise as possible. They must be accompanied by an abstract of not more than 100 words, for publication in Australian Science Abstracts.

2. Papers should be in double-spaced typescript, with ample margins, and on one side only of the paper. Footnotes are to be avoided.

3. The use of italics should be restricted to generic and specific names, foreign words, and titles of periodicals.

4. The cost of author's corrections to proof above what the Council considers a reasonable amount must be borne by the author.

5. All references should be listed at the end of the paper, arranged either alphabetically or chronologically, under authors' names, or numbered serially in order of first mention in the text.

Examples of the respective forms of citation:—

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5. C. FENNER. The Physiography of the Werribee River Area *Proc. Roy. Soc. Vic.*, n.s, xxxi. (1), pp 176-313. 1918

The corresponding references in the text should be "Fenner (1918)," and "(5)" respectively.

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Articles I II IV VII VIII IX XI and XII have been prepared in the Science Departments of the Melbourne University and contributions to the cost of publication have been made from the University Publications Fund

[PROC. ROY. SOC VICTORIA, 58 (N S), PTS I-II, 1947]

ART. I.—*Note on the Pollen of Nothofagus Gunnii (Hook) Oerst.*

By ISABEL C. COOKSON

[Read 12th April, 1945.]

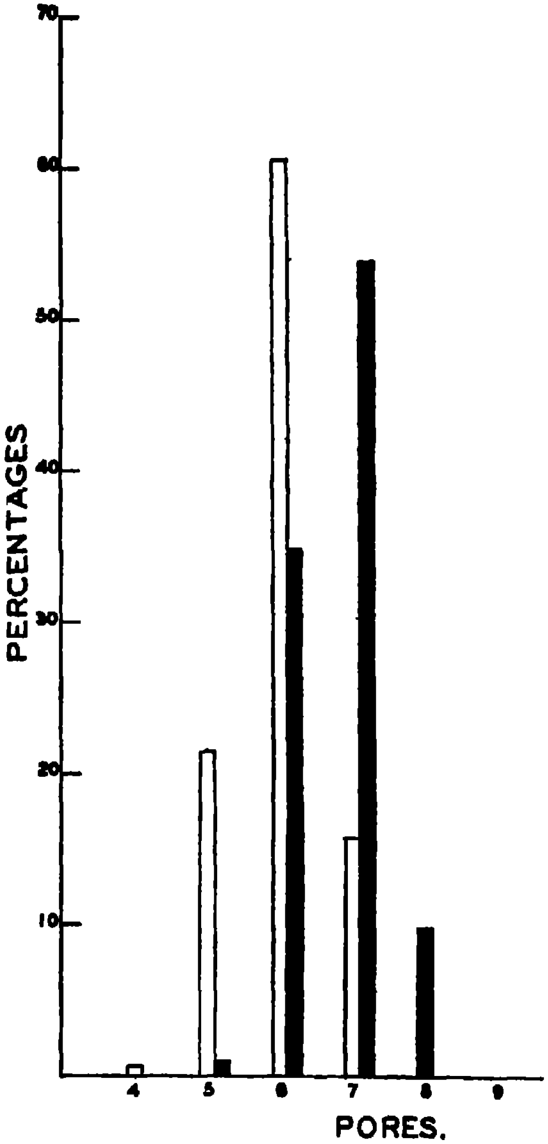
Nothofagus is represented in the flora of eastern Australia and Tasmania by three species. Of these *N. Moorei* (F. Muell.) Maiden, is restricted to New South Wales and southern Queensland, *N Cunninghami* (Hook.) Oerst. to Victoria and Tasmania, whilst *N. Gunnii* (Hook.) Oerst. occurs in Tasmania only. The pollens of *N. Cunninghami* and *N. Moorei* were described by Miss L M. Cranwell in 1939 (Rec. Auck. Inst. Mus. Vol. 2, No. 4, pp 184, 185). In this article the pollen of *N. Gunnii* is discussed.

Unlike the pollens of *N. Cunninghami* and *N. Moorei*, which are of Cranwell's *N. Menziesii* type, the pollen of *N. Gunnii* is of the *N. fusca* type (Cranwell, *loc. cit.* p. 185).

Description of Grain.—Almost circular in polar view; size-range 25·5–39μ, the average being about 31μ Pores 3–8, exceptionally 3, mainly 5–7, the majority 6; from one locality (3, table 1) 7-pored grains predominated. Pores shallower than in grains of *N. fusca*, 2·6μ deep, 1·3–2μ wide, and 8–9μ long. Exine approximately 1·3–1·75μ, not so strongly thickened around the pores as in *N fusca*, sculpture clearly defined, papillae less closely set than in *N. fusca* and rather more strongly developed. Cell contents dense, numerous starch grains present.

Locality	Collector	Date	Collection
1. Cradle Mountain, Tasmania	P R H St. John and O. Romcke	—	National Herbarium
2 Head Mersey River, Tasmania	Mrs C. E. Perrin .	January, 1922	University Herbarium
3 Track to Lake Fenton, Tasmania	A J Ewart	January, 1927	University Herbarium

Locality	Grains Counted	Pore Number					
		3	4	5	6	7	8
		%	%	%	%	%	%
1	748	0·1	1·5	31·8	52·0	14·1	0·53
2	248		0.8	21·8	60·7	15·7	..
3	460	..	..	0·65	34·7	54·0	9·78



Pore-frequencies in pollens of *N Gunnii* ☐ Loc. 2 ■ Loc. 3

Habit.—*N. Gunnii* is a deciduous, much-branched shrub, 5–8 feet in height.

Distribution.—Restricted to high altitudes towards the western region of Tasmania.

Flowering Period.—December.

[Proc. Roy. Soc. Victoria, 58 (N.S.), Pts. I.-II., 1947.]

Art. II.—*The Resistance of Some Australian Timbers to Decay by Mine Fungi.*

By SHIRLEY WEBB, M.Sc.

[Read 14th June, 1945]

Introduction

Very little mycological work has been done in Australia on the decay of mine timbers. This paper describes some investigation carried out on Australian mine fungi, with particular reference to their ability to cause decay of Australian hardwood timbers. The fungi discussed were all obtained in pure culture from decayed mine timber or from fruiting bodies present in a lead-zinc mine at Broken Hill. An attempt was made to discover which fungi were responsible for the main decay of timbers in the mine and which were the most prevalent.

The Fungi

Coniophora cerebella Pers, *Polyporus zonalis* Berk, *Trametes serialis* Fr., *Poria xantha*, Lind. non Fr., and *Merulius pinastri* Fr. are the wood-destroying fungi which were isolated and identified. Others were isolated in culture and found to cause considerable decay but have not so far been positively identified. Throughout this paper all colours written in italics are taken from Ridgway's Colour Standards and Colour Nomenclature (18).

Coniophora cerebella was isolated from decayed mine timber more frequently than any other wood-destroying fungus. It thrives in damp localities and is found commonly in mines and cellars throughout the world. This fungus gives rise to a dark-brown rot which can spread rapidly under moist conditions and its presence must be regarded very seriously. Hardwoods and softwoods are attacked indiscriminately and even the densest hardwoods are not immune to decay by this fungus. Its typical olive-brown warted sheets of fructification and black twine-like strands were seen spreading copiously in all the damp parts of the mine Basidiospores from these fructifications measured from 7–11 × 5–9μ, with an average of 9·1 × 6·7μ. This is the first record of the undoubted occurrence of *C. cerebella* in Australia. Scott (20) reported considerable trouble with jarrah (*E. marginata*) and Red Gum (*E. rostrata*) paving blocks and considered that the decay was probably due to this fungus

Polyporus zonalis was found to be the cause of serious white-pocket rot in the hardwoods, particularly in very moist situations. In America this fungus is known to give rise to a white-pocket rot of hardwoods, including Oak, and is widespread in the tropics, causing decay in tea and rubber plants. Brown (4) reports that *Polyporus rugulosus*, which is synonymous with *P. zonalis*, is present in very moist parts of the mines in South Africa. Dr. T. W. Bowen was good enough to forward a specimen of one of these fruiting bodies and it agreed in all details with the Australian form. He stated in a private communication that he had found it on mine timbers only, never above the ground, both in Southern and Northern Rhodesia and that it was undoubtedly in the copper mines of the Belgian Congo. He thought it was the most virulent wood-destroying fungus he had encountered. Cooke (10) notes that *P. zonalis* has been found on dead wood in Victoria and Queensland.

P. zonalis is able to form copious typical fruiting bodies underground and many perfect specimens were seen and collected. The tough leathery fruiting bodies have a smooth maize-yellow hymenium and narrow incurved cream edge when young. The hymenium darkens as it becomes older and when dry is *flesh-ocher* to *vinaceous-tawny* in colour, Ridgway (18) while in section the colour is lighter, from *maize-yellow* to *pinkish-buff*. The upper surface is zoned and velvety and usually pale-yellow to warm-brown in colour. Encrusted cystidia are common in the hymenium and are considered by Bose (3) to be the most characteristic feature of this fungus.

It should perhaps be pointed out here that Oregon (*Pseudotsuga taxifolia*) was formerly used almost exclusively in the mine from which the fungi were isolated. However, owing to difficulties of supply during the last war, some Australian hardwoods were substituted. Although these timbers proved more resistant to decay than the Oregon underground, it was not until very recent years that they began to replace it to any extent. This replacement has now been accelerated by the practical exclusion of imported softwoods from the Australian market. Considering the presence of so much Oregon in the mine, it was not surprising to find wood-destroying fungi which are typical softwood rotters and would not be expected under normal conditions in Australia. The most common of these is *Trametes serialis*, which was found most often attacking Oregon, but was also seen to cause a brown rot of hardwoods. *T. serialis* is well known in Britain as the most important cause of decay of imported Oregon, but this is the first time it has been recorded in Australia. In America it is responsible for considerable brown rot of softwoods in buildings and in storage. Pilat (17) has reported that this fungus is found frequently in the coal mines at Pribram in Czechoslovakia.

Many cream to chalky white fruiting bodies, ranging from small cushions to perfect bracket shapes, were seen in the mine. They became discoloured on bruising and showed tinges of brown on ageing and were thought at first to belong to *Trametes serialis*. However, pure cultures obtained from many of these were very different from *T. serialis* in culture; in fact, they resembled much more closely cultures of *Polyporus fumosus* Fr. as described by Cartwright (7). Similar cultures were obtained frequently from decayed timber showing brown rot. Until definitely identified, they will be referred to as *Trametes* species.

Poria xantha was also isolated from decayed Oregon in the mine although not as consistently as *T. serialis* and the *Trametes* sp. (A1 and D6). According to Cartwright and Findlay (8) who give a detailed account of the two fungi, *P. xantha* is the frequent cause of much decay in the woodwork of hot houses in Great Britain. It is also one of the principal fungi responsible for the decay of roofs of paper mills in Canada, but its presence has not been recorded before in Australia. The poroid fructification was found occasionally in the mine. It is resupinate and spreads as a thin sulphur yellow layer over the surface of the wood. The pores are normally small and rounded but occasionally become irregular and more elongated. The basidiospores are hyaline and allantoid and range from $3–7 \times 1 \cdot 5–2 \cdot 5\mu$, the average size being $4 \cdot 8 \times 2\mu$. The fructification is characterized by a sweet odour reminiscent of lemons. Badcock (1) noted this and recorded the scent as sweet limonene or almost lemon.

Merulius lacrymans, the dry rot fungus, was not seen or isolated from the mine timber. However, another species of *Merulius* (*M. pinastri*) was found to be very widespread on Oregon, causing considerable brown rot. It was not seen to attack any hardwood in the mine, even when this stood in immediate contact with Oregon badly decayed by this fungus. Cartwright and Findlay (8) record *M. pinastri* as a fungus of minor importance on softwoods in Great Britain. It is not often described or mentioned as a wood-destroyer. However, Burt (5), who described the fruiting bodies in detail, stated that they were found on decaying wood and bark, usually coniferous. Brown (4) mentions a species of *Merulius* that is common in the South African mines at relatively high temperatures but does not give any description. She also notes the absence of *M. lacrymans* from the same mines.

M. pinastri forms large perfect fruiting bodies in the mine, bracket-shaped or circular, according to their position on horizontally or vertically placed timber. They are usally found in the damper part of the mine associated with widespreading fluffy mycelium, which is white at the edges, but brown in the older portions. The young fruiting bodies have a thick rolled creamy white edge surrounding the *pinard yellow* hymenium which covers little tubercles or very short teeth. The teeth lengthen as the fruiting bodies age and become *olivaceous brown* in colour. Spores are yellow-brown and oval, measuring 3–5 × 2–3μ with an average size of 4 × 2·5μ. The whole fruiting body is very soft and flabby when gathered, and the tissue of the pileus is yellow and stringy. Pure cultures were obtained from the fruiting bodies, but never from decayed timber. Growth was extremely slow in culture and, in making isolations from decayed wood, the fungus was always overwhelmed by faster growing moulds.

Several other basidiomycetes were obtained in pure culture from decayed mine timbers, but have not yet been identified. One of these, referred to subsequently as D2, causes a brown rot and appears to be almost as virulent a wood-destroyer as *Coniophora cerebella.*

Inoculation Experiments

EXPERIMENTAL PROCEDURE

Experiments were carried out to determine the comparative resistance of a number of species of Australian hardwoods to decay by the mine fungi. The experimental procedure differed somewhat from the standard method of testing the decay of timbers, in which oven-dried blocks are placed under sterile conditions on a young mycelial mat of the fungus growing on malt agar in special Kolle flasks. In this type of test, the blocks are sterilized by the oven-drying alone, and not by subsequent heating in an autoclave. It is claimed that the extra heating in the moist atmosphere of the autoclave tends to soften the wood, and thus makes it less resistant to decay by wood-destroying fungi. However, in an experiment carried out to test this, the loss of weight in unautoclaved blocks of messmate placed directly on the mycelial mat of *C. cerebella* was even greater than that in the autoclaved blocks subjected to attack by the same fungus (see Table 5). The fungal mat was not grown on malt agar, but on soil to which 10 per cent. of the accelerator, recommended by Badcock (2), had been added. This accelerator is made up of 50 parts maize meal, 30 parts bone meal, 17 parts potato starch, 2 parts sucrose, and 1 part wood ash by weight. When the blocks were autoclaved, the experimental procedure was always the same and each timber was subjected to attack under similar conditions, hence the results should be strictly comparable. Kolle flasks were not available for these experiments, and the soil method of Leutritz (16) was used. This method appears preferable, as the conditions of the experiment approximate more closely to the natural condition of the mine.

Five hundred grams of oven-dry soil were placed in screw-top jars of 1 litre capacity. Water was then added and mixed thoroughly with the soil, the percentage varying with the experimental series, usually 25 or 30 per cent. Two blocks of the timber under test were imbedded in the soil in each jar, leaving one corner projecting. (For some experiments larger jars had to be used, with 800 grams of soil and four blocks instead of two.) The lids were placed loosely on the jars, which were then sterilized for 30 minutes on three successive days in an autoclave at one and a half atmospheres pressure. After the final sterilization, the projecting corner of the blocks was inoculated with the appropriate fungus from a young culture on malt agar. The caps were then screwed down tightly and the jars kept for six months in an incubator room at approximately 25°C.

The experimental blocks were taken from sound seasoned truewood and were of uniform size, 2 × 1 × 1 inches, with the length running across the grain of the timber. They were oven-dried at 102–104°C. for four days, weighed and placed oven-dry in the jars. In the standard test, a period of eighteen hours is recommended for oven-drying. It was found that this was not long enough for the complete drying-out of blocks of the heavier timbers, which lost considerably in weight after the first day. Since any timber will go on losing weight in very minute quantities over an extended period of time, it was decided to take the oven-dry weight after four days, by which time the weight was approximately constant. At the end of the experiment, the blocks were removed from the jar, freed carefully from adhering soil and mycelium, and weighed immediately. They were then oven-dried again. Appreciable weight was still being lost by the fourth day. By the eighth day, loss in weight was negligible, and therefore oven-drying was carried out over a period of eight days instead of four at the end of the experiment. The percentage loss in oven-dry weight, based on the original oven-dry weight, was taken as a measure of the amount of decay. Controls were run with each series, the procedure for these differing only in the absence of any inoculation. The final oven-dry weights of the control blocks served as a check against any decay by intruding soil fungi.

THE TEST FUNGI.

As many different species and isolations of wood-destroying fungi from the mine as possible were used in the inoculation tests in order to determine the most virulent forms, those still unidentified are designated by numbers and letters alone. The following list sets out the forms used:—

Coniophora cerebella—B2 and B11.
Merulius pinastri—M16
Polyporus zonalis—M3
Trametes serialis—B9.
Trametes sp.—A1 and D6
Poria xantha—A8 and A9.
Polystictus versicolor—P2.
Unknown—A3.
Unknown—B9A.
Unknown—D2.

Polystictus versicolor has not been found in the mine, but is included in standard laboratory experiments for the determination of resistance to decay of hardwoods on account of its virulence as a wood-destroyer. It is a white rot fungus which is very widespread in Australia, and which is found in mines all over the world. The culture used here was obtained from a fruiting body found on a rotten log in Victoria.

Coniophora cerebella proved to be the most virulent of the fungi in attacking the hardwoods, but the unknown D2 also showed itself to be a very potent wood-destroyer, causing definite decay in the more resistant hardwoods. The *Trametes* sp. (cultures A1 and D6) and the unknown A3 caused some decay of the denser hardwoods and very considerable decay of the lighter timbers tested.

Contrary to expectations, the decay caused by *Polyporus zonalis* was insignificant in most cases. This fungus was always seen in extremely moist situations in the mine, and it is thought that the moisture content of the experimental blocks was not high enough to permit this moisture-loving fungus to become really active.

Great difficulties were experienced in inoculating timber with *Merulius pinastri*, and although many attempts were made, success was reached with only a few of the timbers tested. In cases where the fungus did grow, however, it attacked the softwoods readily and proved to be a surprisingly virulent destroyer of hardwoods, in contrast to the related species, *M. lacrymans*. It is known from former experience that *M. lacrymans*, although so potent a wood-destroyer, is extremely sensitive in culture. It will stand little disturbance with an inoculating needle, and is easily killed by slight increases of temperature above the low optimum temperature. This sensibility in culture, combined with its extremely slow growth, explains the difficulty experienced in inoculating timber with this fungus.

Poria xantha and *Trametes serialis*, both typical softwood rotters, were unable to produce decay in the denser hardwoods, but caused definite rot of the lighter ones.

THE TEST TIMBERS.

The principal hardwoods used in the mine to replace the softwood (oregon) are blackbutt, messmate, and river red gum, but owing to practical difficulties of supply, many other timbers occur in lesser quantities. Samples sent down to Melbourne for specific determination included red bloodwood, mountain grey gum, tallow-wood, forest red gum, red mahogany, spotted gum, and brush box, in addition to the three species mentioned above. (The common names of timbers used in this paper are those listed as standard common names in " The Nomenclature of Australian Timbers " (21).)

Little data based on laboratory experiments are available on the durability of Australian timbers. Cummins and Dadswell (11), in discussing the main pole timbers of Australia, stated that the figures for pole life were based largely on opinions or general results, and that no detailed records were available. They placed the timbers in three classes, according to their durability. In selecting timbers to be used for tests against the mine fungi, types were chosen from these three classes, in addition to the three main hardwood timbers of the mine. Those selected are as follows:—

Callitris glauca—Cypress pine
Eucalyptus capitellata—Brown stringy bark.
E. maculata—Spotted gum.
E. microcorys—Tallow-wood.
E. obliqua—Messmate.
E. pilularis—Blackbutt.
E. regnans—Mountain ash.
E. rostrata—River red gum.
E. saligna—Sydney blue gum.
Pseudotsuga taxifolia—Oregon.

Cypress pine was classified by Cummins and Dadswell as "very durable," tallow-wood and river red gum as "durable," and spotted gum, messmate, and blackbutt as "less durable." Oregon was included in the tests for comparison with the hardwoods on account of its former widespread use in the mine.

Two series of experiments were run for each timber, one in which the initial moisture content of the soil was 25 per cent, the other 30 per cent. All experiments ran for a period of six months.

Eight blocks of each timber were subjected to attack by each fungus in each series. The percentage loss in oven-dry weight was determined, and the average for the eight blocks taken as the percentage loss in weight for a particular timber when attacked by the fungus in question.

In experiments such as these, the timbers are exposed to the wood-destroying fungi under very favourable conditions for attack Thus the rate of decay is probably considerably accelerated However, the comparative resistance to decay can be determined in this way in a relatively short time. Under the more natural and fluctuating conditions in the mine, it is likely that decay would take place more slowly Valuable information on this point would be obtained by carrying out tests in the mine itself with samples of the different timbers.

It should be pointed out here that in each case timber from one source only was tested Timbers of one particular species may vary considerably in density and toughness, and in its resistance to decay. In order to obtain really conclusive results in tests of this nature, samples of each timber should be taken from five or six different localities. However, the extensive facilities for carrying out such varied and widespread investigations were not available. The results obtained at least give an indication of the behaviour that can be expected from the different timbers when placed under conditions where decay is likely to occur Further work with timbers from varied sources is in hand.

The attack by *Coniophora cerebella* (B11) on all timbers has been chosen as a typical example Complete figures are given for timbers of a high, medium, and low resistance when exposed to this fungus (see Table 4 and Graph 1). Graphs 2 and 3 show the comparative effect of six typical fungi on all the timbers tested.

MOISTURE CONTENT OF THE SOIL AND BLOCKS.

The moisture content of the timber varies tremendously in different parts of the mine. In the vicinity of those parts where ore is actually being removed and is replaced by sand which is flooded in with water, the timber is actually waterlogged. In other localities, particularly in the main stopes away from active removal of the ore, the timber is much drier. Decay is influenced largely by the moisture content of the timber. Timber with a moisture content of less than about 20 per cent. will not decay to any extent, because there is not sufficient moisture for the growth of the fungus. Timber which is completely waterlogged will not decay because there is insufficient oxygen for the growth of the fungus. Between the two extremes, decay is possible. The optimum moisture content of the timber for decay depends on the species of the wood-destroying fungus, but is said to vary from 30 per cent. to 60 per cent. of the oven-dry weight of the timber. For instance, *Merulius lacrymans* is able to attack timber with a very low moisture content, whilst *Coniophora cerebella* requires a much higher moisture content.

Difficulty was experienced in ascertaining optimum moisture conditions for the fungi under test, and in obtaining similar moisture conditions in the blocks in each timber. Different timbers, or even different specimens of the same timber, will take up varying amounts of moisture under identical conditions. Cartwright (6) in discussing the decay of sitka spruce by *Trametes serialis* noted the practical impossibility of obtaining samples of wood, which will, under the same conditions, take up equal amounts of water. This makes it doubtful whether extreme accuracy in controlling these factors would not be wasted.

In the early stages of the work, an experiment was carried out with the purpose of determining the most suitable percentage of moisture for the soil in the jars. The non-resistant timber, mountain ash, was exposed to attack by three different isolations of the potent wood-destroyer *Coniophora cerebella* at different soil moisture contents. The cultures used were B2 and B11, already mentioned as having been isolated from decayed oregon and B3, which was obtained from brown rot in messmate. Four series were carried out with each fungal culture; in the first series the moisture content of the soil was 20 per cent., in the second 25 per cent., in the third 30 per cent., and in the fourth 35 per cent. The results are set out in Table 1.

TABLE 1.—*Eucalyptus regnans*—EXPOSED TO THREE DIFFERENT STRAINS OF *Coniophora cerebella* FOR SIX MONTHS; WITH VARYING MOISTURE CONTENTS OF THE SOIL.

Percentage Moisture Content of—		Percentage Loss in Weight Due to Decay by—		
Soil	Blocks	B 2	B 3	B 11
20	60·8	48·1	48·3	56·8
25	63·5	41·2	52·0	64·6
30	82·7	45·0	48·0	64·1
35	98·9	33·5	31·5	36·8

The figures in the second column, referring to the percentage moisture contents of the blocks, were obtained by taking the average moisture content of the controls for each series at the end of the experiment. This is seen to rise with increase in moisture content of the soil and reaches nearly 100 per cent. in the 35 per cent. series. The amount of decay was considerable in every case, but did not vary greatly in the first three series. In the fourth, however, the amount of decay was significantly lower for each isolation, and the statistical analysis of the results showed the effect of moisture content to be highly significant The moisture content in these blocks was obviously above the optimum even for the moisture-loving *C. cerebella* (see Graph 1).

It was decided, in view of these results, to use the two series with medium moisture contents of the soil for all future experiments. In the first series, the amount of water added to the soil was 25 per cent. of its oven-dry weight. In the second series 30 per cent. was added. The percentage of moisture taken up from the soil by the blocks varied considerably and could not be controlled accurately. The lighter timbers, such as mountain ash, messmate, brown stringy bark, oregon, and cypress pine took up much more moisture than did the denser timbers blackbutt, river red gum, spotted gum, and tallow-wood. An indication of the moisture content of the blocks during the experiment was obtained from the moisture content of the controls at the end of the experiment. Figures for these are given in Tables 2–5, together with the loss in weight due to decay in the inoculated blocks. Extra control jars were set up in one experiment, and these were opened after different periods of time, from one to six months, and the blocks used for moisture content determinations. From these it was seen that the amount of moisture in the blocks was approximately the same at the end of the experiment as during the first and following months. This was not the case, however, in the inoculated blocks. When decay took place, the timber took up more moisture and became spongy and less dense. Thus as a rule, the greater the decay, the higher was the moisture content.

A comparison of Graphs 2 and 3 will show the difference in the amount of decay caused by several of the fungi in the two series of soil moisture contents. In the majority of cases, the amount of decay was somewhat greater in the blocks of the series with soil at 25 per cent. moisture content. This even held for the attack by the moisture-loving *Coniophora cerebella,* except with the timber Sydney blue gum, where considerably more decay was present in the series with 30 per cent. soil moisture content than with the 25 per cent. series.

The percentage of moisture in the blocks seemed to be suitable for decay by all fungi except *Polyporous zonalis.* The amount of decay caused by this fungus in both series of experiments was never great, and it is thought that this was probably due to an insufficiency of moisture. *P. zonalis,* unlike other mine fungi, caused extensive decay only in those parts of the mine where particularly moist conditions prevailed, and where the timber was dripping with moisture. It would, therefore, be desirable to test cultures of this fungus on blocks in soil with a considerably higher moisture content than that used in the tests already described. Preliminary tests have indicated that considerably more rot would be caused by *P. zonalis* at a soil moisture content of 45 per cent.

No statistical analysis of the difference in resistance of different species of timber was carried out, since each species was represented by material from only one source. However, the results obtained indicated that the species examined fell into three groups of resistance, namely, high, medium, and low resistance, which appeared very well demarcated. Since the different species differed in the variability of the loss in weight as well as in the mean loss obtained with each fungus, each was analysed separately and each fungus in each moisture content regarded as a different treatment. Significant differences of treatment means were worked out for each species of timber, the significant differences being based on the average variance of treatment means for the species. These figures are included in Tables 2 and 3. Thus, the significant difference at the 10 per cent. level for mountain ash is 12·41—this means that if the difference between the mean losses caused by any two fungi attacking this timber is higher than 12·41, there is a significant difference in the virulence of those fungi towards it. For example, *C. cerebella* can be expected to cause more rot of mountain ash than can *Poria xantha,* but the latter fungus cannot be expected to cause more rot than the unknown fungus A3.

EXPERIMENTAL RESULTS.

Owing to the bulk of the tables, complete results for all experiments are not included, a summary of the results is given instead, in Tables 2 and 3. Complete figures for the attack by *Coniophora cerebella* on a timber from each of the three groups of resistance, high, medium, and low, are given in Table 4. Graphs 2 and 3 show the comparative effect of six typical fungi on all the timbers tested.

TABLE 2.—SUMMARY OF THE MEAN LOSS OF WEIGHT CAUSED BY THE TEST FUNGI IN EACH TIMBER MOISTURE CONTENT OF THE SOIL 25 PER CENT

Fungus	Loss in weight per cent based on loss of oven-dry weight (Mean value of 8 blocks)									
	Mountain Ash	Messmate	Brown Stringy Bark	Sydney Blue Gum	Blackbutt	Spotted Gum	River Red Gum	Tallow wood	Cypress Pine	Oregon
Coniophora cerebella B2	48.5	32.0	22.9	12.7	7.2	14.1	17.3	6.8	6.8	62.3
Coniophora cerebella B11	64.5	28.1	21.9	16.1	17.5	16.5	12.5	11.0	5.7	60.8
Merulius pinastri M18			40.1	1.5			8.4		17.4	41.4
Polyporus zonalis M3		5.6	7.8	1.9	2.3		2.0	2.2		12.6
Trametes serialis B9	40.9	11.5	3.7	5.5	2.8	7.2	2.2	2.5	3.1	63.9
Trametes Sp A1		17.8	33.1	9.7	8.6	4.6	13.1	4.0	2.1	49.5
Trametes Sp D6		45.1	12.4	12.0	4.7	10.5	2.6	6.7	19.7	55.6
Poria xantha A8			2.4	2.8	2.2	2.8	1.6		4.8	38.5
Poria xantha A9	26.5	18.0	2.8	1.4	2.7	2.3	1.6		23.6	45.2
Polystictus versicolor P2					2.9	4.8	1.8	1.9	8.1	
Unknown A3	22.7	25.7	7.6	10.0	9.3	4.2	12.9	4.9		28.6
Unknown B9A	40.2	9.6	3.0	2.4	2.7	1.0	2.0	2.0	9.0	60.3
Unknown D2						9.8	12.1	13.4	38.1	
Controls	1.4	1.0	2.2	1.2	1.7	0.7	1.[illegible]	1.8	2.3	4.2
Significant difference of treatment means at 1 per cent level	12.41	12.18	8.15	4.09	4.06	3.10	5.36	[illegible].74	16.76	11.90
Significant difference of treatment means at 5 per cent level	9.17	8.08	6.09	3.08	3.24	[illegible].43	4.04	3.06	12.33	8.95
Average moisture content percentage of controls	76.2	65.6	55.2	46.5	4[illegible].4	28.8	34.0	29.4	40.9	36.7
Mean of treatments (loss percentage) for all fungi used	42.1	21.5	14.3	6.0	5.7	7.1	6.9	5.6	12.1	46.3

TABLE 3.—SUMMARY OF THE MEAN LOSS OF WEIGHT CAUSED BY THE TEST FUNGI IN EACH TIMBER. MOISTURE CONTENT OF THE SOIL 30 PER CENT.

Fungus.	Loss in weight per cent., based on loss of oven-dry weight. (Mean value of 8 blocks.)									
	Mountain Ash.	Messmate.	Brown Stringy Bark.	Sydney Blue Gum.	Blackbutt.	Spotted Gum.	River Red Gum.	Tallow-wood.	Cypress Pine.	Oregon.
Coniophora cerebella B2 ..	44·0	23·4	..	29·3	7·0	6·1	6·7	4·9	7·2	43·4
Coniophora cerebella B11 ..	47·6	25·2	18·7	32·1	13·9	8·9	12·9	7·1	5·1	39·4
Merulius pinastri M16 ..	..	..	23·2	..	..	..	..	3·4	19·6	33·1
Polyporus zonalis M3	..	..	14·5	..	..	..	1·9	2·5	..	18·1
Trametes serialis B9	..	24·1	7·0	1·8	3·9	4·1	2·3	2·1	8·8	56·0
Trametes Sp. A1	..	18·3	..	4·0	7·1	2·8	2·7	5·8	6·6	29·6
Trametes Sp. D6	..	..	16·6	.	..	..	4·5	5·7	19·6	56·3
Poria xantha A5	..	19·4	..	1·5	1·9	1·1	1·6	..	24·4	34·7
Poria xantha A9 .. .	..	19·9	2·9	1·5	2·2	1·0	1·6	2·1	10·2	31·3
Polystictus versicolor P2 ..	..	..	..	..	..	6·5	1·7	2·3	3·7	..
Unknown A3	..	21·2	..	4·6	4·1	5·2	4·1	3·0	2·7	24·1
Unknown B9A	..	14·2	..	2·0	2·0	1·4	1·6	2·1	2·8	..
Unknown D2	..	..	..	..	..	7·6	9·4	9·8	3·9	..
Controls	0·6	1·4	1·7	1·3	1·5	1·3	1·4	2·8	3·4	3·8
Significant difference of treatment means at 1 per cent. level ..	12·41	12·18	8·15	4·09	3·06	3·10	5·36	2·74	16·76	11·90
Significant difference of treatment means at 5 per cent. level ..	9·17	8·98	6·09	3·08	2·24	2·35	4·04	2·06	12·23	8·95
Average moisture content percentage of controls	83·7	60·2	78·8	41·6	58·7	37·6	33·6	18·4	98·4	77·9
Mean of treatments (loss percentage) for all fungi used	45·8	20·7	18·5	9·6	5·2	4·7	4·3	4·2	9·6	36·2

TABLE 4.—EFFECT OF *Coniophora cerebella* B11 ON TEST TIMBERS AT 25 PER CENT. MOISTURE CONTENT OF SOIL.

Timber.	No of Block	Original Oven-dry Weight	Weight on Removal from Jar	Final Oven-dry Weight.	Loss of Weight in Grams	Loss of Weight Per Cent	Final Moisture Content Per Cent.	Average Loss of Weight Per Cent.	Average Moisture Content Per Cent.
Mountain Ash	98	24·51	20·47	9·32	15·19	62·0	119·6	64·6	99·1
	100	23·83	17·55	8·63	15·20	65·8	103·4		
	73	24·42	18·38	9·95	14·47	59·3	84·7		
	129	22·36	13·92	7·58	14·78	66·1	83·6		
	97	22·48	14·17	7·15	15·33	68·2	98·2		
	108	24·77	16·21	7·90	16·87	68·1	105·2		
Controls*	7	22·81	40·30	22·28	0·53	2·4	81·3	1·4	76·2
	46	26·77	42·61	26·61	0·16	0·6	60·1		
	9	23·35	41·66	23·06	0·29	1·2	80·6		
	58	24·37	42·79	24·12	0·25	1·1	77·4		
	8	22·79	43·04	22·36	0·43	1·9	92·5		
	54	22·25	41·37	22·00	0·25	1·0	87·9		
	19	23·72	38·02	23·38	0·34	1·4	62·6		
	28	23·40	37·42	23·09	0·31	1·3	62·5		
Messmate	169	21·66	36·26	15·47	6·19	28·6	134·4	28·1	133·9
	170	21·61	36·32	15·38	6·23	28·8	136·2		
	171	21·54	35·87	15·35	6·19	28·7	133·7		
	172	21·72	37·39	16·41	5·31	24·4	127·8		
	173	21·55	35·38	15·41	6·14	28·5	129·6		
	174	21·72	36·14	15·30	6·42	29·6	136·2		
	175	21·78	36·80	15·70	6·08	27·9	134·4		
	176	21·76	37·17	15·54	6·22	28·6	139·2		
Controls	185	22·23	37·37	21·95	0·28	1·3	70·3	1·0	65·6
	186	23·36	38·52	23·14	0·22	1·0	66·4		
	187	22·65	38·16	22·43	0·21	0·9	70·1		
	188	22·47	37·41	22·24	0·23	1·0	68·2		
	189	22·84	36·32	22·69	0·15	0·7	60·1		
	190	23·22	35·44	23·10	0·12	0·5	53·5		
	191	22·91	38·30	22·66	0·25	1·1	69·0		
	192	22·94	37·90	22·67	0·27	1·2	67·2		
Brown Stringybark	49	18·76	25·88	16·16	2·60	13·9	60·2	21·9	64·9
	50	18·02	22·97	14·10	3·92	21·8	62·9		
	51	18·24	23·52	14·42	3·82	20·9	63·1		
	52	18·35	23·33	14·53	3·82	20·8	60·6		
	53	17·87	23·22	13·93	3·94	22·0	66·7		
	54	17·78	21·74	13·10	4·68	26·3	66·0		
	55	17·65	22·72	13·33	4·32	24·5	70·4		
	56	17·63	22·28	13·17	4·46	25·3	69·2		
Controls	41	17·88	27·56	17·50	0·38	2·1	57·5	2·2	55·2
	42	18·07	27·77	17·64	0·43	2·4	57·4		
	43	18·12	27·70	17·72	0·40	2·2	56·3		
	44	18·31	27·39	17·87	0·44	2·4	53·3		
	45	18·36	28·20	17·97	0·39	2·0	56·9		
	46	18·61	28·48	18·20	0·41	2·2	56·5		
	47	18·77	28·07	18·38	0·39	2·1	52·7		
	48	18·75	27·64	18·34	0·41	2·2	50·7		
Blackbutt .	157	25·31	35·40	20·31	5·00	20·0	74·3	17·5	62·5
	158	25·20	32·87	19·24	5·96	23·7	70·8		
	159	25·21	37·32	21·61	3·60	14·3	72·7		
	160	25·24	34·50	20·40	4·84	19·2	69·1		
	161	25·28	35·08	22·59	2·69	10·6	55·2		
	162	25·49	34·77	22·20	3·29	12·9	56·6		
	163	25·58	33·61	21·87	3·71	14·5	53·7		
	164	25·65	28·56	19·40	6·25	24·4	47·2		
Controls .	189	26·28	37·99	25·86	0·42	1·6	46·9	1·7	45·4
	190	26·41	38·38	25·98	0·43	1·6	47·7		
	191	26·57	38·08	26·18	0·39	1·5	45·5		
	192	26·22	38·91	25·75	0·47	1·8	51·1		
	193	26·07	36·91	25·61	0·46	1·8	44·1		
	194	26·19	36·96	25·77	0·42	1·6	43·5		
	195	26·14	37·33	25·61	0·53	2·0	45·8		
	196	26·29	35·83	25·88	0·41	1·6	38·4		

* These jars served as controls for all fungi

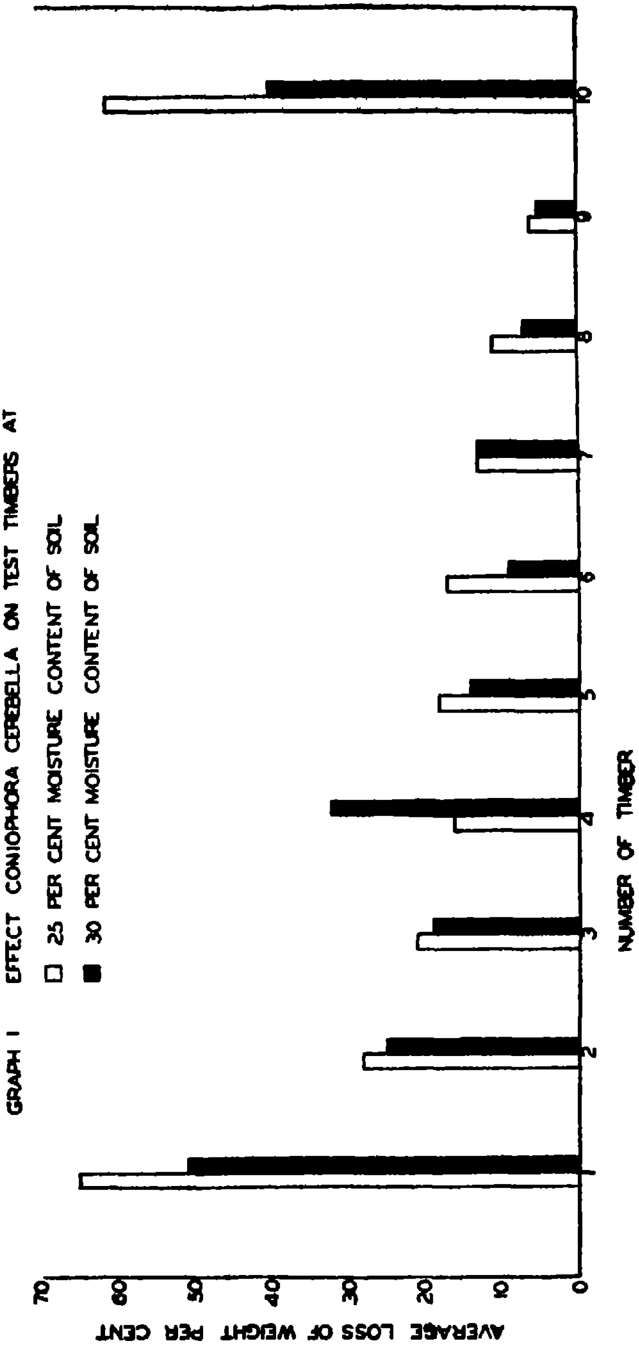
TABLE 5—EFFECT OF *Coniophora cerebella* ON UNAUTOCLAVED BLOCKS OF MESSMATE.

Fungus	No of Block	Original Oven-dry Weight	Weight on Removal from Jar	Final Oven-dry Weight	Loss of Weight in Grams	Loss of Weight Per Cent	Final Moisture Content Per Cent	Average Loss of Weight Per Cent.	Average Moisture Content Per Cent.
Coniophora cerebella B11	99	22·88	32·80	15·02	7·86	34·4	118·4	34·2	112·2
	105	22·89	35·55	16·64	6·25	27·3	113·6		
	95	22·98	33·40	15·71	7·27	31·6	112·6		
	98	22·78	30·42	14·26	8·52	37·4	113·3		
	91	23·01	24·03	11·74	11·27	49·0	104·7		
	94	22·83	26·77	13·04	9·79	42·9	105·3		
	97	22·69	39·69	19·38	3·31	14·6	104·8		
	100	22·61	32·76	14·40	8·21	36·3	127·5		
Controls	5	22·45	28·38	22·38	0·07	0·3	26·8	0·6	32·5
	6	22·62	28·56	22·53	0·09	0·4	26·8		
	7	22·40	28·32	22·30	0·10	0·4	27·0		
	8	22·21	28·08	22·11	0·10	0·5	27·0		
	90	23·27	32·10	23·07	0·20	0·9	39·1		
	92	22·91	32·12	22·74	0·17	0·7	41·2		
	93	23·37	30·57	23·24	0·13	0·6	31·5		
	96	22·74	31·82	22·60	0·14	0·6	40·8		

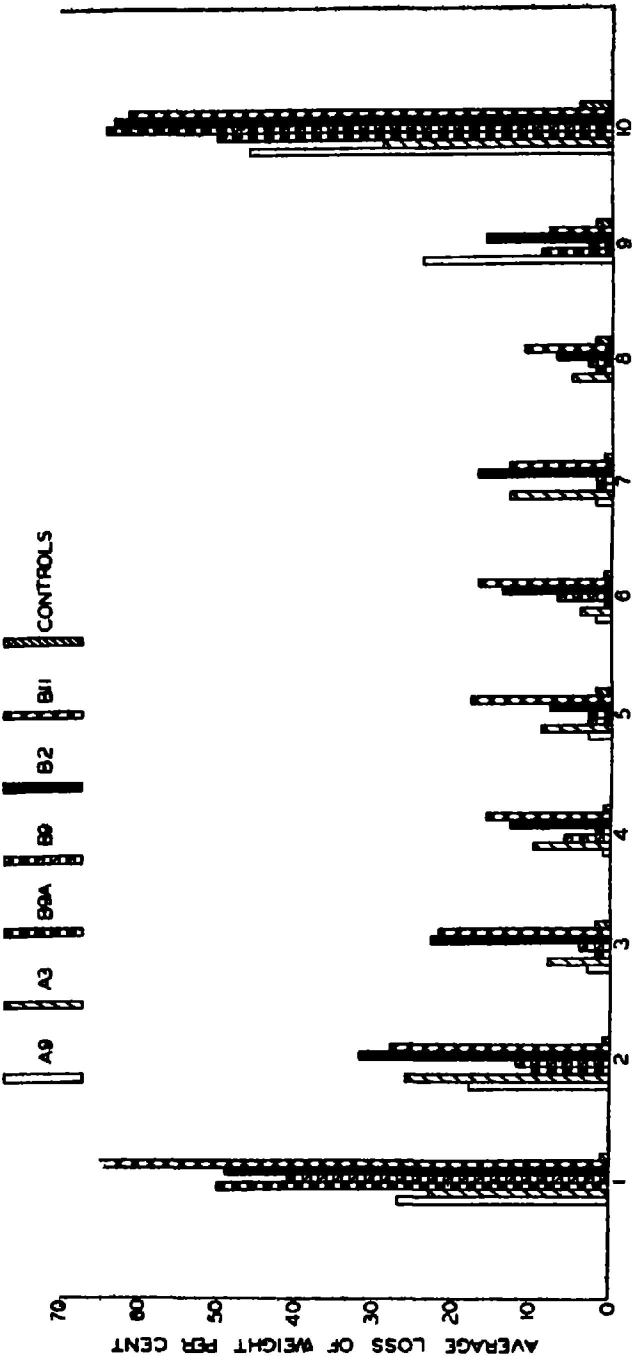
Key for Graphs

The test timbers are numbered as follows —

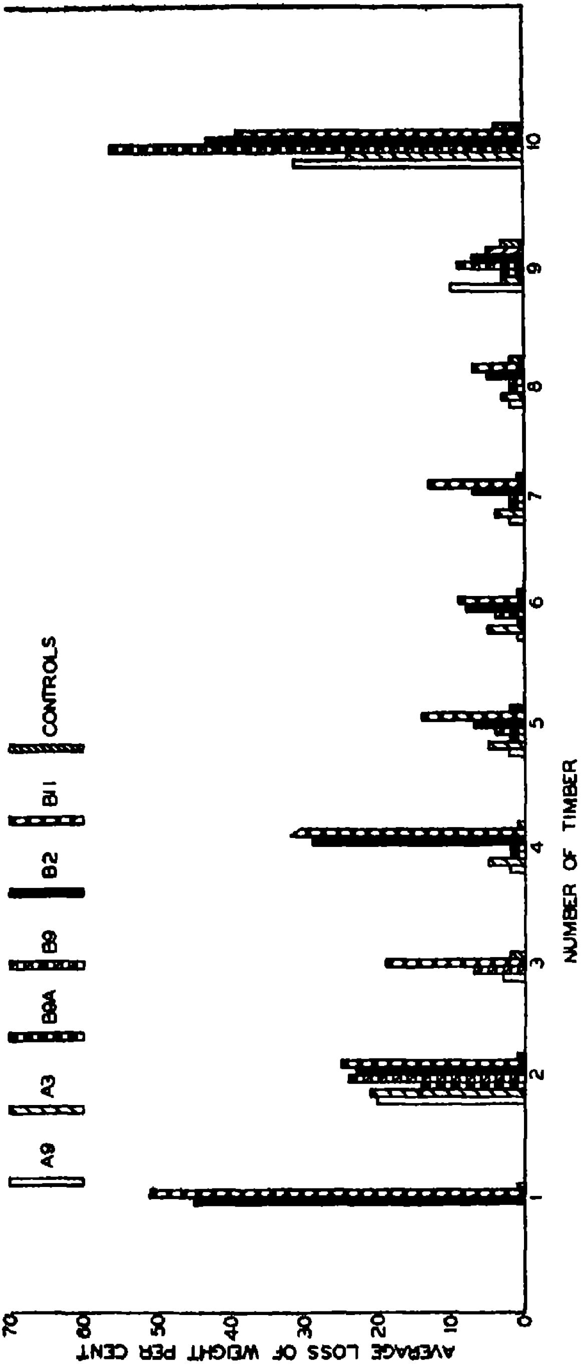
1 *Eucalyptus regnans*—Mountain ash.
2 *E. obliqua*—Messmate
3 *E. capitellata*—Brown stringy bark
4 *E. saligna*—Sydney blue gum
5 *E pilularis*—Blackbutt
6. *E. maculata*—Spotted gum
7. *E. rostrata*—River red gum
8. *E microcorys*—Tallow-wood
9. *Callitris glauca*—Cypress pine
10. *Pseudotsuga taxifolia*—Oregon


GRAPH I EFFECT CONIOPHORA CEREBELLA ON TEST TIMBERS AT
□ 25 PER CENT MOISTURE CONTENT OF SOIL
■ 30 PER CENT MOISTURE CONTENT OF SOIL
AVERAGE LOSS OF WEIGHT PER CENT
0
10
20
30
40
50
60
70
NUMBER OF TIMBER
1
2
3
4
5
6
7
8
9
10

GRAPH 2 EFFECT OF VARIOUS FUNGI ON TEST TIMBERS AT 25 PER CENT MOISTURE CONTENT OF SOIL



GRAPH 3 EFFECT OF VARIOUS FUNGI ON TEST TIMBERS AT 30 PER CENT MOISTURE CONTENT OF SOIL



Discussion of Results

Blackbutt, spotted gum, river red gum, and tallow-wood were by far the most resistant timbers tested, and they exhibited very much the same behaviour towards each of the fungi used. The statistical analysis showed that the differences in loss of weight due to decay were not significant and did not allow of comparison between these timbers. *Coniophora cerebella* and the unknown fungus D2 caused the greatest loss in weight, but even with these virulent wood-destroyers decay was not really severe. *Poria xantha, Polyporus zonalis*, and the unknown B9A did not give rise to significant loss of weight in any of these timbers, whilst *Trametes* sp. (A1 and D6) and the unknown A3 caused slight decay. The decay due to *Trametes serialis* and *Polystictus versicolor* was negligible except in the case of spotted gum, where attack was noticeable but not severe. *Merulius pinastri* caused an average of 8 per cent. loss in weight in river red gum, but practically none in tallow-wood. Its effect on blackbutt and spotted gum is not known, as inoculations of the fungus against this timber were not successful.

Mountain ash proved to be the least resistant of all the Australian hardwood timbers tested. It was attacked very readily by each fungus to which it was exposed, whether it were a hardwood or softwood destroyer. *P. xantha* and *T. serialis* decayed this timber to a considerable extent, and after six months exposure to attack by *C. cerebella* and the unknown B9A, the blocks could be crumbled easily in the hand.

Messmate was not attacked quite as readily as mountain ash, but did not prove to be a resistant timber. The softwood rotters, *P. xantha* and *T. serialis*, and the unknown brown rot forms (A3 and B9A) were able to cause appreciable brown rot in this timber, whilst attack by *C. cerebella* and *Trametes* sp. D6 was even more severe.

Brown stringy bark was more resistant than the two previous timbers to attack by *P. xantha* and *T. serialis*, but was definitely decayed by *Trametes* sp. (A1 and D6), *C. cerebella, P. zonalis*, and *M. pinastri*. Brown stringy bark was one of the few hardwood timbers with which the inoculation of *M. pinastri* was successful, and it proved very susceptible to attack by this fungus, 40 per cent. loss of weight being caused in the one series and 23 per cent. in the other.

Sydney blue gum was resistant to attack by *P. xantha* and *P. zonalis* and the unknown B9A, and only showed very little decay with *T. serialis* and *Trametes* sp. (A1). However, in the series with the higher moisture content of the soil, it was no more resistant to decay by *C. cerebella* than was messmate.

The only Australian softwood timber to be tested was cypress pine (*Callitris glauca*). For reasons that are discussed later, the results with this timber were very variable. With 25 per cent. moisture content of the soil, considerable rot was caused in most blocks of cypress pine by *P. xantha* (A9), by *Trametes* sp. (D6, but not A1), by *M. pinastri*, by *C. cerebella* (B2), but not by the virulent strain B11, and the most severe rot by the potent rotter D2. With 30 per cent. moisture content of the soil, however, D2 caused practically no rot at all, and the two isolations of *C. cerebella* only slight rot. Most rot was caused in this series by *P. xantha* A8, *Trametes* sp. (D6), and *M. pinastri*.

In view of the fact that oregon was used formerly almost exclusively in the mine, tests were carried out with this timber for comparison with the Australian hardwoods. Extreme decay resulted in every case, with hardwood and softwood rotter alike, except with *P. zonalis* where rot was significant but not high. Oregon proved to be less resistant than mountain ash, the least resistant of all the Australian timbers tested.

The classification of pole timbers according to their durability as set out by Cummins and Dadswell has already been mentioned. Although used for very different purposes, and under different conditions from mine timbers, pole timbers are subjected to conditions favourable for decay at the ground line, and a durable pole timber, just as a durable mine timber, must be resistant to decay in contact with the ground. Cummins and Dadswell placed tallow-wood and river red gum in the "durable" class, but spotted gum and blackbutt, together with messmate, were classified as "less durable." It is interesting to note that in the experiments described above, both spotted gum and blackbutt proved to be quite as resistant to attack by wood-destroying fungi as tallow-wood and red gum. Messmate behaved according to expectations from this classification, and proved considerably less resistant to attack than the above-menioned timbers. The results with messmate are not in agreement with those of Findlay (15), who included it when testing the natural resistance to decay of some Empire timbers. His figures for the decay of messmate were remarkably low compared with the Australian figures. When attacked by *Coniophora cerebella,* the loss of weight after a period of eight months was 6·5 per cent. in Findlay's experiment. In contrast to this, reference to Table 2 shows that messmate lost 28 per cent. of its weight when exposed to attack by *C. cerebella* for six months with the soil method. Findlay was using the standard Kolle flask method, in which the unautoclaved blocks are placed directly on the mycelial mat, but the difference in experimental method cannot be responsible for such a remarkable difference in the loss of weight per cent. In a test mentioned earlier, in which unautoclaved blocks of messmate were placed directly on the mycelial mat of *C. cerebella,* in a comparable way to the Kolle flask test, the loss of weight was 32 per cent., a little higher even than that achieved in the soil method experiment.

Findlay considered tallow-wood a resistant timber. He obtained slight loss of weight, but regarded this as due to loss of extractives and not to decay. In the experiments described in the present paper, there was invariably some loss of weight in the controls, and this was considered to be due to loss of water soluble extractives. It can be noted that the figures for the loss of weight in the tallow-wood controls were very slightly higher than those in other hardwoods.

Mountain ash, which proved the least resistant of the hardwood timbers tested, was not included by Cummins and Dadswell in any of their durability classes. It is not regarded as a suitable pole timber, and is generally known to be very susceptible to decay. Dadswell (12) pointed out that mountain ash is not suitable for use in contact with the ground, and the experiments with the exposure of this timber to the mine fungi confirm this statement.

Cypress pine was classed as "very durable" in the ground. Cummins and Dadswell (13) have shown that its durability is due largely to a volatile acid, for which the name callitric acid was proposed. It was doubtful at the outset, therefore, whether the type of test used here, with its prolonged heating in the oven and autoclave would prove suitable for such a timber. A certain amount of the volatile acid was bound to be lost during heating, and the resistance to decay thus diminished. As was expected, the results were variable, some blocks proving quite resistant, while others were strongly attacked by the same fungus. The average of the loss in weight of the eight blocks seldom gave a true picture of the results. In many cases, three blocks in one jar lost little weight, while the fourth was decayed considerably: (Larger jars were used in this experiment and four blocks were placed in each jar.) The variable results were no doubt due to the unequal loss of the volatile acid and did not give a reliable indication of the real durability of this timber.

Summary

Chief among the wood-destroying fungi isolated from decayed mine timber or from fruiting bodies found in an Australian zinc mine were *Coniophora cerebella* Pers., *Polyporus zonalis* Berk., *Trametes serialis* Fr., *Poria xantha* Lind non Fr., and *Merulius pinastri* Fr. Others were isolated but not identified. *C. cerebella* and an unidentified isolation, D2, were the most potent of the wood-destroying fungi.

Inoculation experiments, using soil as a medium, were carried out to test the comparative resistance of a number of Australian timbers to decay by these fungi. Percentage loss in weight, based on the oven-dry weight, was used as a criterion of the amount of decay.

Two series of experiments were carried out for each timber. In the first series, the moisture content of the soil was 25 per cent., in the second 30 per cent. The lower percentage of moisture gave better conditions for decay in the majority of cases, but there were exceptions.

Blackbutt (*Eucalyptus pilularis*), spotted gum (*E. maculata*), river red gum (*E. rostrata*), and tallow-wood (*E. microcorys*) were outstanding in their resistance to fungal attack, and although decayed to some extent by *Coniophora cerebella*, the attack was not nearly as severe as in the case of the poorer timbers.

Mountain ash (*E. regnans*) was decayed very readily by every fungus tested. Messmate (*E. obliqua*) was not attacked quite as readily, but did not prove to be a resistant timber.

Brown stringy bark (*E. capitellata*) and Sydney blue gum (*E. saligna*) were very susceptible to attack by the potent wood-destroyer *C. cerebella*, but were considerably more resistant than mountain ash and messmate to the other less virulent fungi.

Results with cypress pine (*Callitris glauca*) were variable, probably due to unequal loss of the volatile acid to which it owes its durability.

The important softwood oregon (*Pseudotsuga taxifolia*) was decayed even more readily than mountain ash.

Acknowledgments

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Appendix

CULTURAL CHARACTERISTICS OF THE MINE FUNGI.

Coniophora cerebella Pers. (B2 and B11) are two isolations of *C. cerebella* resembling the type described by Cartwright and Findlay (8) as the "Idaweiche" variety. Growth commences as long white tufts from the inoculum and the colour develops quickly, passing from *straw yellow* through various shades of brown. The whorled clamp connections characteristic of *C. cerebella* can be seen on about the fourth day, just behind the tips of the young aerial hyphae. They are not seen in old cultures. Hyphae are straight and broad, usually about 4μ in diameter, but they may reach 10μ. Strand formation is rapid, but whereas the strands on malt agar usually remain light in colour, in cultures on wood blocks they become very dark and resemble closely those formed in nature. A tough velvety tubercular hymenial layer, from *Dresden brown*, *raw umber* to *Saccardo's umber* forms very frequently in older cultures, particularly in those on wood blocks, with the production of oval to almost globose brown basidiospores. In B2, these measure 6 × 4–7μ with an average of 7·5 × 5μ.

Merulius pinastri Fr. (M16).—Pure cultures of this fungus were obtained from the fruiting bodies, but never from rotting wood. The aerial mycelium on malt agar is at first thick, white, and fluffy, but as growth proceeds the mycelium in the centre turns *Pinard yellow* to *Empire yellow* and then various shades of brown, from *amber brown* to *Sudan brown*, *Argus brown*, or *cinnamon brown*. It always remains very soft and fluffy and never becomes tough. Hyphae are from 1·5 to 4μ in width and do not bear clamp connections. The mycelium acquires a powdery appearance due to the formation of numerous secondary spores, similar in size and shape to the basidiospores, but borne terminally or in an intercalary fashion on the mycelium. They are oval and brown in colour, measuring from 3·5–6 × 2–5μ with an average of 4·2 × 3·2μ. Fine silky strands cling to the wall of the test tube or in wood block cultures pass from the blocks out on to the neighbouring soil and up the wall of the jar. Growth in culture is extremely slow, a colony only reaching a diameter of approximately 2 cm. in fourteen days.

Polyporus zonalis Berk. (Syn: *Polyporus rugulosus*).—The cultural characteristics of this white rot fungus have been described by Davidson, Campbell and Vaughan (14). Growth on malt agar is at first very long, white and silky. The aerial hyphae are straight and broad, up to 4μ in diameter, and do not bear clamp connections. Also typical are the mosaic-like sheets formed by the union of short hyphae. The aerial mycelium soon flattens, becoming *pinkish-buff* in colour and forming a dense flannel-like mat. Small velvety *pale orange yellow* lumps appear here and there and show on microscopic examination the encrusted cystidia so common in the hymenium of the fruiting body. Basidiospores have not been seen in culture.

Trametes serialis Fr. (B9).—The cultural characteristics of this fungus have been described in detail by Cartwright and Findlay (8) and by Snell (19). The Australian isolations agree very closely both as to macroscopic and microscopic characters. Growth on malt agar is at first somewhat sodden and appressed, but soon becomes more cotton-woolly. The mycelium is white, but later shows tinges of *salmon colour* and *light salmon orange* and small patches of *bistre brown*, particularly at the top of the slope where growth is more luxurious than in the lower portion and tends to plug the tube. Numerous single clamp connections are seen on the aerial and submerged mycelium. Chlamydospores are present and are usually oval and intercalary, but are occasionally rounded and terminal. They range from 8·5–21·5 × 6·5–11·5μ, with an average of 12 × 8μ. Fine foliose fructifications develop, sometimes after a week or ten days, particularly on the inoculum, and produce typical basidia and basidiospores. The basidiospores are oval and hyaline, and range from 4–6 × 2–3μ.

Trametes sp. (A1 and D6).—It has already been mentioned in the course of the paper that many cultures obtained both from fruiting bodies and from decayed wood resembled those of *Polyporus fumosus*, as described by Cartwright (7), although the fruiting bodies were thought to belong to *Trametes serialis*. Typical of these cultures, which are referred to as *Trametes* sp. throughout the paper, are the isolations A1 and D6. A1 was obtained from hardwood showing brown rot, D6 from brown rot in oregon. Growth on malt agar is at first white, soft, and downy, but soon becomes tufted and very powdery and light-buff in colour. The powdery appearance is due to the formation of very numerous chlamydospores on the aerial mycelium. Many single clamp connections are present and they sometimes give rise to branches. Hyphae are mostly fine, 1–2μ in diameter, but may reach a width of 5 or 6μ. Rhomboidal crystals are common.

The chlamydospores are mostly terminal and often borne in clusters, but are sometimes intercalary. In cultures of A1, the chlamydospores range from 5–9μ in diameter, with an average of 7·5μ. In D6, they range from 5–10 × 4–7μ, with an average of 7·3 × 5·4μ. Chlamydospores are also very numerous in the tissue of the fructification. Small velvety pads of fructification are formed in culture of both A1 and D6. They usually turn yellow to brown in colour when formed on malt agar, but when produced on wood blocks are often large and cushion-like, and remain white to cream for some months before turning *bistre brown*. They produce basidia and hyaline basidiospores in a hymenium-like layer. In A1, the basidiospores are 4–5 × 2·5–4μ, with an average size of 5–2·5μ. Findlay and Cartwright (9) describe the cultures of *P. fumosus* as being soft, thin, and farinaceous to powdery, at first white then pale *cartridge buff*, with numerous secondary spores averaging 8–10μ, borne in tufts. Cartwright (7) gives further details of the culture of *P. fumosus*, mentioning the above features, and also the presence of rhomboidal crystals and the formation of hymenial surfaces with normal basidia and basidiospores and hyphae measuring 1–5μ in diameter, though mostly 1·5–2μ. It can be seen that there are very strong resemblances between the cultural characters of *Polyporus fumosus* and those of A1 and D6. However, as no cultures of *P. fumosus* are available for comparison, it is thought advisable to refer cultures of A1 and D6 to *Trametes* sp.

Poria xantha Lind non Fr. (A8 and A9).—These are two isolations of *Poria xantha* from brown rot in oregon. The cultures agree very closely with the description given for this fungus by Cartwright and Findlay (8). A very pronounced sweet lemon-like odour characterizes the cultures, and is noticeable by the sixth or seventh day. This confirms the observations of Badcock (1) who reports that *P. xantha* has an odour resembling liminene, or almost lemon. This odour is also a feature of the fructification.

Growth on malt agar is fine and cobwebby, and never luxurious. Fine white or yellow strands pass out from the inoculum over the surface of the agar. Hyphae are fine, and single clamp connections are numerous in aerial and submerged mycelium. A pored hymenial layer soon forms at the top of the slope and gradually covers the greater part of the surface. In cultures of A8 it is chalky-white to cream, whereas in cultures of A9 it is *picric yellow* to *pale lemon yellow* in colour. Typical small allantoid basidiospores are formed abundantly on the hymenium. In A8 they range from 3–7 × 1·5–2·5μ in size, with an average of 4·7–2μ. Measurements for basidiospores in A9 are almost identical, with a range of 3–7 × 1·2–2·5μ and an average of 4·7 × 2μ.

Unknown A3 was isolated in culture from decayed messmate with light-brown stringy to spongy rot. The culture on malt agar is thick, flat, white, and felted, and even old cultures rarely show any change of colour except for a slight yellowing. No secondary spores are seen in culture, either on malt agar or on wood blocks. Single clamp connections are numerous on the submerged mycelium

Unknown B9A is an unidentified basidiomycete isolated from oregon with brown stringy rot. Early growth in culture on malt agar is thick, white, and fluffy, but the mycelial mat becomes felted with age It remains pure white even in old cultures, Single clamp connections occur frequently, and numerous rounded, oval, or pear shaped chlamydospores are present, ranging from 8–16 × 6–12μ, with an average size of 11 ×8μ. Rather spiky coral-like white abortive fructifications form around the inoculum and produce small oval hyaline basidiospores. The measurements of these are from 4–6 × 2–3μ, with an average of 5 × 2·5μ.

Unknown D2 was isolated frequently from hardwood timber with a dark-brown stringy rot, but was not identified. A pure white cotton-woolly mat forms rapidly on malt agar and soon blocks the whole tube. There is little alteration in appearance as the culture ages, except for a change to *cream colour* or *light-buff*. The hyphae are extremely broad, usually from 6–20μ in width, and show short blunt branches. No clamp connections are formed Round to oval chlamydospores are very common, and range from 9–14 × 5–11μ, with an average size of 11·5 × 7·8μ. When crushed the culture has a pronounced mushroom odour

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[Proc. Roy. Soc. Victoria, 58 (N.S.), Pts. I.-II., 1947.]

Art. III.—*A Fossil Beaked Whale from Lakes Entrance, Victoria.*

By M. F. GLAESSNER, Ph.D.

[Read 14th June, 1945.]

Abstract

The rostrum of a large beaked whale, derived from the Kalimnan (Pliocene) of Gippsland, is described. It is conspecific with a ziphiid rostrum described by Chapman from Western Victoria which is recognized as *Mesoplodon longirostris*. The taxonomy and stratigraphic distribution of *Mesoplodon* are discussed. Physiological explanations of peculiar structural features of the ziphiid rostrum are reviewed.

Introduction

The first report on a rostrum of *Mesoplodon* (Cetacea, Fam. Ziphiidae) in the Tertiary of Victoria was published by F. Chapman (1917). He described one well-preserved and one fragmentary specimen from the Kalimnan (Pliocene) of Grange Burn, near Hamilton, Western Victoria.

During the early stages of the excavation of a shaft near Lakes Entrance, Gippsland, about 1942, another rostrum of a beaked whale, of rather different general appearance, was found Mr. Chapman, to whom the fossil was submitted, identified it as *Mesoplodon*, apparently conspecific with that described by him in 1917. Permission to examine and describe the specimen was obtained by the present writer from Mr. C. S. Demaine, of Melbourne, who also supplied detailed information about its occurrence. Mr. Chapman's valuable type specimen and a skull of *Mesoplodon grayi* described by Brazenor (1933) were made available for comparison by the late Mr. D. J. Mahony and Mr. R. A. Keble, of the National Museum, Melbourne.

Genus **Mesoplodon** Gervais, 1850

This much-discussed genus includes nine living species (Raven 1937). Most of the fossil remains assigned to it consist only of parts of the cranial rostrum. Detailed studies of numerous Recent skulls have shown that the most important specific characters recognizable in the rostrum of *Mesoplodon* are:—

(1) The presence or absence of the basirostral (maxillary alveolar) groove;

(2) The relative position of the premaxillary and maxillary foramina at the base of the rostrum;

(3) The lateral outline of the base of the rostrum,

(4) The relation of bones participating in the formation of the region of the antorbital notch.

In connection with (1), it may be mentioned that vestigial teeth are present in the gums of the upper jaw in some forms, and that the shape and position of the large mandibular teeth are taxonomically important features. However, teeth do not usually occur in their original connection with fossil cranial rostra.

The significance of the character mentioned under (2) was explained by Raven (1937, p. 6), who stated:—

> "The conspicuous maxillary foramen which affords an exit for the principal branch of the nervus infraorbitalis is situated close to the lateral border of the premaxillary bone, where the latter is constricted at the base of the rostrum The premaxillary foramen in *Mesoplodon* is always located at the rostral border of the very slight

> depression that marks the site of the ventral spiracular, or premaxillary sac. In some species of *Mesoplodon* the premaxillary foramen is in advance of the adjacent maxillary foramen, in other species behind the maxillary foramen This depends upon the size and shape of the sac. In *M. europaeus* the sac is relatively long, consequently the premaxillary foramen is decidedly in advance of the maxillary foramen."

As the shape and the state of ossification of the median and distal parts of the rostrum are known to vary greatly with age and sex, they do not possess any taxonomic value This was recognized only after a considerable number of fossil representatives of *Mesoplodon* had been described. The published descriptions and figures of most of these fossils do not indicate any differences in essential specific features. Differences previously considered as specific and even generic are almost exclusively those distinguishing Recent individuals of different sex or age.

At the present time not more than one fossil species of *Mesoplodon* can be definitely recognized and characterized. This was first stated by Abel (1905, p. 111) who, after examining 18 fossil specimens of *Mesoplodon* from Antwerp, came to the following conclusion:—

> "Il ne peut subsister de doute que toutes les différences qui existent entre les rostres de Mésoplodontes fossiles connus jusqu'à présent, ne suffisent pas pour fonder de nouvelles espèces, a plus forte raison différents genres. La forme et les différences de grandeur, ainsi que le degré d'ossification du vomer varient extrêmement; on serait obligé, en poussant la minutie aussi loin que R. Owen, du Bus et Capellini, de distinguer, dans le Bolderien d'Anvers, non moins de 15 a 18 espèces."

Abel placed not less than 25 species, described under six generic names, in the synonymy of *M. longirostris,* but only about 15 of these are based on material which is comparable with the type. Kellogg (1928, p. 61) has pointed out that the number of Recent species of *Mesoplodon* makes it likely that several species of this genus existed contemporaneously in late Tertiary time. This probability, however, does not justify the use of specific names based entirely on characters which are known to be variable within the limits of Recent species.

MESOPLODON LONGIROSTRIS (Cuvier), 1923

(Plate 1, Text fig 1)

1823—***Ziphius longirostris*** Cuvier, Ossements fossiles, p. 356, pl. 27, figs. 9, 10.

1851—***Mesodiodon longirostre*** (Cuvier): Duvernoy, Ann. Sci. Nat, Zool, ser. 3, vol. 15, p. 60, pl, fig 5 (holotype re-figured).

1852.—***Dioplodon beccarii*** Gervais, Zool. Pal. Franç, vol 2, p. 38 (not seen).

1856.—***Ziphius longirostris*** Cuvier. Owen, Quart J Geol. Soc, vol 12, p. 288, fig. 24

1864.—***Belemnosiphius compressus*** Huxley, Quart. J. Geol. Soc., vol. 20, p. 393, pl. 19, figs A–D.

1868—***Belemnoziphius recurvus*** Du Bus, Bull Acad. Roy. Belg, sér 2, vol. 25, p 630

1870—***Ziphius longirostris*** Cuvier. Owen, Palaeont. Soc., vol. 23, pp 6, 7.

1870—***Ziphius gibbus*** Owen, ibid, p 17, pl. 2, fig. 2, pl 3, fig. 3.

1870—***Ziphius angustus*** Owen, ibid, p. 19, pl. 3, figs 1, 2.

1870.—***Ziphius angulatus*** Owen, ibid, p. 20, pl. 4, figs. 1, 2.

1870—***Ziphius medilineatus*** Owen, ibid., p 22, fig. 10, pl. 4, fig. 3

1870—***Ziphius tenuirostris*** Owen, ibid., p. 24, pl. 5, figs. 1, 2.

1870.—***Ziphius compressus*** Owen, ibid., p 25, pl. 5, fig. 3.

?1876.—***Belemnosiphius prorops*** Leidy, Proc Acad. Nat. Sci Philadelphia (1876), p. 81.

?1877—***Dioplodon prorops*** Leidy, J. Acad. Nat. Sci. Philadelphia, vol. 8, ser. 2, p. 226, pl. 30, figs 3, 4

1885.—*Dioplodon longirostris* (Cuvier): Capellini, Mem. Roy. Accad. Sci. Bologna, ser. 4, vol. 6, p. 294, pl. 1, figs. 1-3.

1885.—*Dioplodon gibbus* (Owen): Capellini, ibid., p. 295, pl. 1, figs. 4,5.

1885—*Dioplodon medilineatus* (Owen): Capellini, ibid., p. 298, pl. 1, fig. 12.

1885.—*Dioplodon tenuirostris* (Owen): Capellini, ibid., p 296, pl. 1, figs 6-8

1885.—*Dioplodon bononiensis* Capellini, ibid., p. 296, pl. 1, figs. 9-11.

1885.—*Dioplodon senensis* Capellini, ibid., p. 298, pl. 1, figs. 13-18.

1885.—*Dioplodon lawleyi* Capellini, ibid, p 299, pl. 1, figs. 17, 18

1887.—*Dioplodon longirostris* (Cuvier): Lydekker, Catal. foss. Mammals Brit. Mus., vol. 5, p. 68, figs. 13, 14.

1890—*Mesoplodon floris* Newton, Quart. J. Geol. Soc, vol 40, p. 448, pl. 18, fig 7.

1891—*Mesoplodon longirostris* (Cuvier) · Newton, Vetebr. Plioc. Dep. Britain (Mem. Geol Survey), p. 8, fig. 7?

1891—*Mesoplodon tenuirostris* (Owen, *gibbus* (Owen), *angustus* (Owen), *angulatus* (Owen), *compressus* (Huxley) Newton, ibid, p 73

1891—*Mesoplodon floris* Newton, ibid, p 71

p. 371, pl 1, figs 2 6

1891—*Dioplodon farnesinae* Capellini, Mem. R. Accad Sci Bologna, ser. 5, vol. 1,

?1891—*Dioplodon tenuirostris* (Owen) Capellini, ibid, p. 371, pl 1, fig. 7 (very small fragment, *indet.*)

1905—*Mesoplodon longirostris* (Cuvier): Abel, Mém. Mus. Roy. Hist. Nat. Belg., vol 3, p. 110.

1917—*Mesoplodon compressus* (Huxley). Chapman, Proc. Roy. Soc. Vic., vol 30, n s, p 35, pl. 4, figs 1-4; pl. 5, figs. 7-11.

Diagnosis. Rostrum long, narrow, and pointed, resembling in shape that of the living *M. grayi*, slightly inflated in its proximal half, strongly compressed laterally, oval in cross section Length variable Mesorostral ossification well developed, in young specimens only in the distal portion of the rostrum, in adult individuals filling the entire length of the space between the premaxillaries and finally fused with the mesethmoid. Alveolar (basirostral) groove developed as a fairly deep furrow with sharp edges along the flank of the rostrum. Premaxillary and maxillary foramina situated (as in *M. bidens* and *M. mirus*) approximately on the same transversal line, not far behind the "inner notch." The premaxillary foramina are slightly smaller than the maxillary foramina The maxillary ridges are weak. The area of attachment of the palatines ends in a single anterior point The posterior ventral part of the rostrum forms a triangular downward projection most of which was apparently covered by the pterygoids.

Distribution of *Mesoplodon longirostris*

VICTORIA

The new specimen was found in a shaft in allotment 31, Parish of Colquhoun, County of Tambo, Gippsland, less than 1 mile north-east of Lakes Entrance, 6-7 feet below the present surface and at an elevation of about 80 feet above sea level It was resting on the surface of a calcareous bed considered as the top of the Kalimnan (Pliocene) which is in this vicinity about 160-170 feet thick (Singleton 1941, Crespin 1943). The specimen was evidently weathered out of late Kalimnan beds more or less in situ and, subsequently, with some of the hardened fossiliferous matrix still adhering to it, embedded in non-marine post-Kalimnan (Upper Pliocene or Pleistocene) clays which in this area overlie disconformably the Kalimnan strata.

Chapman's specimen came from Grange Burn in Western Victoria, where "the typically Kalimnan beds of MacDonald's and Forsyth's are separated from the underlying Balcombian by a thin nodule bed marking a stratigraphic break" (Singleton 1941, p. 78). The appearance of the specimen shows clearly that it was taken from this nodule bed. The age of Chapman's specimen is believed to be early Kalimnan (Pliocene).

BELGIUM

The locality of the holotype of *M. longirostris* is unknown, but Abel (1905, p. 110) assumed that it came from Antwerp. According to this author, the eighteen specimens of this species from Antwerp examined by him came from the "Bolderien" It appears that Abel followed the stratigraphic classification of the Antwerp Tertiary proposed by van Ertborn who distinguished only two formations, the Bolderien (Miocene) and the Diestien (Pliocene) Later authors divided the Miocene of Belgium into the older Bolderien and the younger Anversien, representing, respectively, the Helvetian (Middle Miocene) and the Tortonian-Sarmatian (Upper Miocene). The presence of equivalents of the next younger stage, the Pontian, in this basin is uncertain A stratigraphic break separates the Anversian from the Diestian (Pliocene).

Remains of fossil whales are known from several zones within the Anversian and Diestian The actual horizons of occurrence of many of these fossils have not been reliably recorded There is, however, little doubt that at least some of the specimens of *M. longirostris* came from the typical grey sands of the Anversian. Abel referred all of them specifically to the Upper Miocene (pre-Diestian). Kellogg (1928, p. 764) listed the Ziphiidae of Antwerp as "Sarmatian" (lower part of Upper Miocene).

CRAG OF EAST ANGLIA

Six of the specimens described by Owen under as many different specific names have since been placed in the synonymy of *M longirostris*, together with another specimen later described by Newton All these came from the "Nodule bed" at the base of the Red Crag (Newton 1891, pp. 72-74). Prestwich referred to a "*Belemnosiphius*" from the Nodule bed at the base of the Coralline Crag. The age of these fossils does not appear to have been defined as clearly in recent publications as in Owen's work, where it is stated that "the rolled and fragmentary Cetacean remains belong to a deposit older than these which, by their testacean fossils, may be truly or strictly defined as 'Red Crag': that the older deposit in question —more or less destroyed and broken up in Suffolk—answers in time, to the better known Belgian 'Sable noir' of the 'Système Diestien' of Nyst and von Koenen" (Owen 1870, p 2). The only correction to be made in this statement is due to a change in stratigraphic classification in Belgium, where the 'Sable noir' is now classed as Anversian. Newton (1891, p. 3) also considers these Crag fossils as "remanié", derived from beds older than the "older Pliocene" Lenham beds, but finding the evidence for their Miocene age insufficient, he refers them to an early Pliocene stage. In view of the generally accepted Plaisancian (Lower Pliocene) age of the Lenham beds, this can be only the Pontian. As far as the Cetaceans are concerned it is difficult to see what objections can be raised against Owen's suggestion of Anversian (Upper Miocene) age of the specimens from the Red Crag.

ASHLEY RIVER PHOSPHATE BEDS OF SOUTH CAROLINA

Although the suggested synonymy of some of the Cetacean remains from these phosphate beds with *Mesoplodon longirostris* is uncertain there seems to be among them at least one specimen (*Dioplodon prorops* Leidy) close enough to Cuvier s species to justify a brief statement on its age The vertebrate bearing phosphate rock named Edisto marl in earlier publications is now considered as residual Hawthorn formation (Cooke 1936 p 114) G M Allen (1926 p 447) found that most of the remains of terrestrial mammals from the phosphate beds belong to Pleistocene species while most of the marine species are of an equally Miocene facies The Hawthorn formation from which the phosphate rock was derived is correlated with the lower part of the Alum Bluff group of Florida (Burdigalian) but may also include higher members of this group (equivalents of Helvetian and Tortonian) Kellogg (1928) places the Ziphiidae from South Carolina in the Sarmatian O P Hay (Second Bibliography of Fossil Vertebrates of North America Carnegie Inst Publ No 390 1930) refers them to the Upper Miocene

PLIOCENE OF ITALY

Remains of Ziphiid whales closely resembling *Mesoplodon longirostris* and probably correctly identified with this species by Abel have been described from a number of localities in the Pliocene of Italy Some of them are in the north eastern foothills of the Apennines and others near Rome (Middle Pliocene)

Description of *Mesoplodon longirostris* from Victoria

The well preserved specimen from Grange Burn was described in some detail and measured by F Chapman (1917) A few additional observations are here recorded The surface of the bone which is stained dark brown is worn smooth but the differences between the original surface the areas of other bones which are lost and the later fractures can be recognized In pits and furrows some soft whitish rock matrix is preserved and small oyster shells adhere in some places to the bone The maxillaries extend about 25 mm laterally from each of the maxillary foramina The ventrally projecting basal portions of the maxillaries are broken off A rougher surface extends ventro laterally over more than half the length of the rostrum About 65 mm from the posterior tip of the vomer on the ventral surface of the rostrum this rougher area widens out in median direction to form a distinct area of attachment for the palatines ending in a single anterior point on either side The premaxillary and maxillary foramina are perfectly preserved

The object described by Chapman (1907 p 38) as a maxillary tooth was removed from the matrix and carefully examined Although it resembled a tooth in its peculiar bluntly conical shape it was found when sectioned to be a concretion without any trace of organic structure Dr F L Stillwell who kindly examined the object found that it consisted almost entirely of limonite

The new specimen from Lakes Entrance is a cranial rostrum preserved from the area of the maxillary foramina to a bluntly rounded anterior end The length of the missing distal part to the tip of the rostrum can be estimated at between 150 and 250 mm. The foramina were filled with ferruginous matrix, but only the left premaxillary foramen is completely preserved. The lateral extensions of the maxillaries are incomplete, particularly on the left side, and the maxillary crests are lost. A coating of ferruginous matrix on the original surface of the bone is visible in the pre-orbital region and on a small portion of the antero-ventral part of the rostrum. The fossil is deeply weathered and fissured, the fissures being partly filled with calcareous matrix. Subsequent weathering of this matrix has widened the fissures It appears that the fossil was originally buried in the Kalimnan calcareous deposit in a slightly broken, cracked, and weathered condition. The sediment penetrated the deep cracks of the bone, while on its surface a ferruginous coating was formed in which molluscan fragments have been preserved. Later, the fossil weathered out of the Kalimnan rock and was subjected to erosion on the surface before being embedded in the yellow clay of post-Kalimnan age Little damage was done in the process of removing it from this sediment, fresh fractures being confined to the right posterior side of the maxillary region and the left side of the anterior part of the rostrum. In the course of the present investigation, a transverse slice about 15 mm thick was cut from the specimen, about 340 mm from its present proximal end

Owing to the deep weathering of the new specimen, little can be added to what is already known of the morphology of the rostrum in *Mesoplodon longirostris* On the dorsal surface the distal spur of the mesethmoid can be vaguely distinguished From this point a dark median line (an infilled sulcus) extends a short distance along the surface of the rostrum. It corresponds to the median furrow which was erroneously considered as an essential specific character of *M. longirostris*, but is not consistently developed in any of the known species of the genus The median proximal part of the ventral surface is exceptionally well prserved in the new rostrum This is the first specimen to show the peculiar triangular crest or keel descending ventrally between the attachment areas of the pterygoids. Published figures indicate that in most or all Recent species of *Mesoplodon* the rostrum is not nearly as deep in this region, its deepest part being normally the tip of the vomer which in ventral views of some skulls can be seen between the tips of the pterygoids In *M longirostris* the postero-ventral side of the rostrum is formed by two laminae, diverging proximally and enclosing at their base the main body of the vomer. Some space between the vomer above and the two laminae below is filled with rock matrix in both Victorian specimens, but in the Grange Burn specimen the projecting ventral part of the laminae is broken off.

Comparisons of measurements and proportions of the two Victorian rostra suggest that the size of the new specimen exceeded that of Chapman's fossil by about one-half. The preserved part of the rostrum is about 450 mm. long, and its original total length can be estimated at about 600-700 mm., corresponding to a skull not less than 3 feet in length The convex dorsal outline and the almost complete preservation of the projecting ventral crest produce the impression of great relative height of the new rostrum. The maximum height in the present state of preservation is 147 mm., the width immediately in front of the "inner notch" is about 80 mm. The greatest width of the mesorostral band is 36 (22) mm., the approximate distance between the centres of the premaxillary foramina is

60 (38) mm., that between the centres of the maxillary foramina is 125-130 (85) mm. [Figures in parentheses indicate corresponding measurements in Chapman's specimen.]

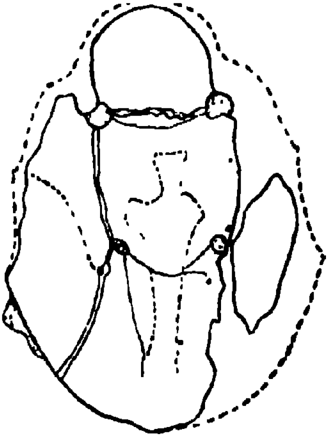

FIG. 1.—*Mesoplodon longirostris* (Cuvier). Transverse section of the rostrum from Lakes Entrance, Victoria. Outline partly restored. 2/3 nat. size.

The transverse section is oval in outline, not unlike those given by Huxley, Owen, and Chapman for *M.* "*compressus*" and by Forbes for *M. grayi* (Forbes 1893, pl. 13, fig. 3; pl. 14, fig. 5). The bones are dense and resemble ivory. Very few larger pores or canals are visible on the polished surface of the cut or in thin sections, but a high porosity becomes evident through capillary action when the specimen is wetted. Three fairly regular gently curved light-coloured bands, about 1 mm. wide, correspond to the matrix-filled cracks on the surface of the specimen. Larger longitudinal canals, circular in section, are found where vertical and horizontal fissures join. Their arrangement is due partly to the regular spacing of the canals which form zones of weakness, and partly to the internal structure of the bone. No definite sutures are visible in section, the components of the rostrum being completely fused. Only a very faint discontinuity in the finer structure of the bone appears to indicate part of the outline of the vomer.

Notes on the Development of the Rostrum in *Mesoplodon*

The peculiar features of the rostrum in beaked whales (*Mesoplodon, Ziphius, Choneziphius*) have been extensively discussed and variously interpreted by a number of authors. Zoologists (Forbes, Fraser, Harmer) investigated the development of the bones in the rostrum, and in particular the comparative anatomy of the mesorostral ossification. Palaeontologists discussed its functional significance. Abel, in his "Palaeobiology of the Vertebrates" (1912) described the ziphiid rostrum as strongly ossified to an ivory-like or porcellaneous mass of bone, with its elements completely fused in adult individuals. In several fossil specimens he found traces of injuries which must have occurred during the life of the individual. He explained the morphological features of the rostrum as adaptations consequent upon its use as a weapon in fights among adult male beaked whales. Injuries, however, are known to occur also in other parts of the body in Cetaceans without inducing adaptive reactions. Even if the Lamarckian view underlying Abel's hypothesis is accepted, it is hardly possible to regard injuries to a bony structure as sufficient evidence of its use as an offensive weapon.

A different explanation was suggested when results of modern experimental pathology were taken into consideration. It was found that a pathological modification of the bone structure to ivory-like density (osteosclerosis), which is frequently accompanied by a general increase in thickness of bones (pachyostosis), corresponds closely to peculiar characters observed in parts of the skeleton of certain fossil Mesosauria, Lacertilia, Ophidia, Sirenia, and Cetacea. F. Nopcsa's pioneer studies in vertebrate palaeo-physiology (1923) and their further development (Sickenberg 1931) led to the conclusion that the change in environment which occurred in the phylogeny of some marine vertebrates was accompanied by peculiarities in the development of their skeleton, among which pachyostosis and osteosclerosis are particularly interesting. They are tentatively attributed to the same causes as the analogous pathological effects, i.e., to reduced thyroid and increased pituitary gland function (hormone secretion). A reduction of oxygen intake and an increase of iodine in the food of originally terrestrial animals becoming adapted to marine life have been suggested as environmental influences likely to cause this type of modification in the skeleton (Sickenberg 1931). Where phylogenetic lineages can be followed, as in the family Halicoridae, a rapid development of pachyostosis and osteosclerosis of parts of the skeleton in the course of evolution is found, followed by gradual decrease.

Slijper, in his monumental work on the comparative anatomy of the whales (1936, p. 475), regards osteosclerosis of the ziphiid rostrum as a normal " functional adaptation." He admits, however, that it could be interpreted alternatively as an "arrostic" phenomenon affecting certain species. He re-defines this term, which was first proposed by Nopcsa, to apply to such anatomical or histological phenomena as are caused by an " unfavourable" adaptation of the metabolism to new environmental conditions (Slijper, l.c.p. 469; see also O. Abel, " Verfehlte Anpassungen bei fossilen Wirbeltieren," *Zool. Jahrb.*, Suppl.-Bd. 15, vol. 1, 1912, p 597).

In a study of the relation between giantism and the development of the pituitary body of the brain as observed in internal casts of fossil skulls and in living animals, T. Edinger (1942) refers to osteosclerosis in whales as one of the bone changes accompanying phylogenetic hyperpituitary giantism. The author states that this relation cannot be interpreted in Lamarckian terms as an adaptive reaction, as the occurrence of giantism is independent of the type of environment and is accompanied by a variety of apparently unrelated changes in bone structure in different types of vertebrates.

The species *Mesoplodon longirostris* has not attracted much attention in the discussion of the important problem of physiological influences on the evolution of the skeleton in marine vertebrates. This is not surprising as this species is known mainly from fragmentary or badly worn rostra. Most of them have been redeposited from older strata, or carried from the open sea to littoral zones of deposition. It is clear that such circumstances would favour the fossilization of strong and heavily ossified bones and would tend to preserve selectively the most strongly osteosclerotic rostra. Nevertheless, there are reasons to believe that this alone does not satisfactorily account for the difference in ossification which the available descriptions of fossil and Recent skulls of *Mesoplodon* appear to indicate. Some of the Recent skulls have been found loose on beaches, preserved in similar circumstances as the fossil specimens, while others are larger and belong to fully-grown individuals, but are not as strongly ossified as some of the fossil rostra. It is, therefore, suggested that osteosclerosis and possibly also pachyostosis of the rostrum are more strongly developed in the extinct *M. longirostris* than in the living representatives of the genus. This suggestion requires confirmation by means of detailed comparative studies, which should lead to interesting conclusions in view of the stratigraphic and phylogenetic relations of this fossil species to a number of others standing between the primitive squalodontids of the Oligocene and the ziphiids. The fact that the new specimen was found almost in situ and in a much less water-worn condition than most of the previously known rostra justifies the expectation that more complete remains of this species will be found in the Kalimnan.

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Description of Plate

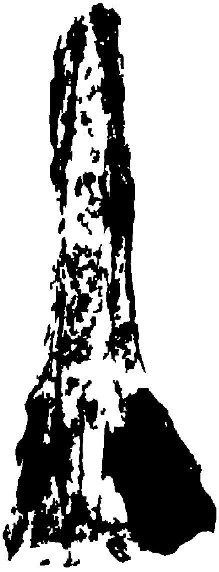
Plate I

Mesoplodon longirostris (Cuvier)

Figs 1 3—Rostrum from Lakes Entrance Victoria 1—dorsal 2—ventral 3 lateral view

Figs 4 5—Rostrum from Grange Burn near Hamilton Victoria 4—dorsal 5—lateral view Type of *Mesoplodon compressus*, Chapman 1917

About ½ nat size Photographs by Mr J S Mann Geology Department Melbourne University Original in Commonwealth Palaeontological Collection Canberra



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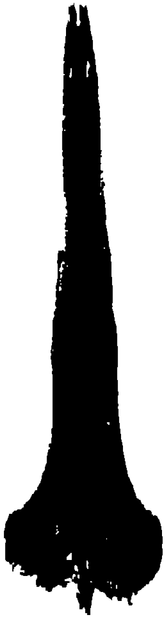

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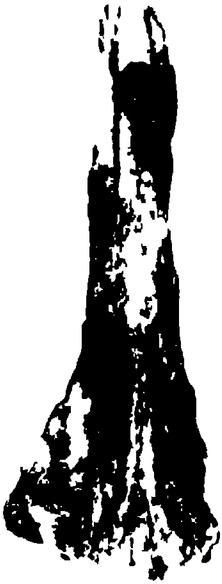

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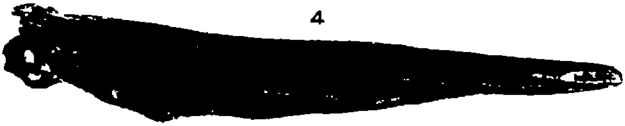

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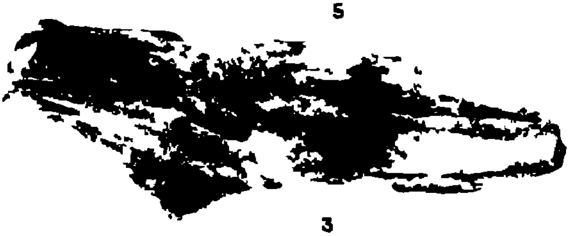

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[Proc Roy Soc Victoria 58 (N S) Pts I II 1947]

Art IV —*Some Features of the Coastline between Port Fairy and Peterborough Victoria*

By E D GILL BA BD

[Read 14th June 1945]

Abstract

Three types of coastline (mobile dune consolidated dune limestone and Miocene marine limestone) are described with comment on the geological succession Further evidence of a relative eustatic fall in sea level of the order of 15 feet is adduced Evidences of both drier and wetter climates have been found

Physiography

The coastline to be described may be divided into three sections according to the dominant geological structure viz —

- Mobile Dune Coast from Port Fairy to Warrnambool
- Consolidated Dune Limestone Coast from Warrnambool to Childers Cove
- Miocene Marine Limestone from Childers Cove to Peterborough

MOBILE DUNE COAST

Bordering the coast from Port Fairy to approximately the boundary of the City of Warrnambool are mobile dunes which consist of calcareous sand similar to the consolidated dune material on which they rest and which is exposed at many places in the vicinity (Mahony 1917 Gill 1943) Behind the mobile dunes are extensive marshes formed by their damming the drainage in some of these are found marine shells proving former sea encroachment The dunes have caused the formation of Belfast Lough and have diverted the Merri River so that 6 miles of its course is roughly parallel to and close to the shore line Parish plans in this area show many streams ending short of the coast at this fringe of coastal dunes (whether mobile or fixed) Dunes formerly mobile but now anchored by marram grass occur along the beach in Lady Bay (Warrnambool Bay) and resting on the consolidated dune limestone within the boundaries of the City of Warrnambool From Lady Bay to a point 2½ miles east of the Hopkins River the mobile dunes also resting on consolidated dune limestone form the coastal fringe Where the mobile dunes end and the cliffs composed wholly of dune limestone begin there is a patch about 6 feet thick of consolidated bedded tuff that has been ejected from the Tower Hill volcano to the west north west This deposit is probably an accumulation in a swale now partially eroded by wave attack

CONSOLIDATED DUNE LIMESTONE COAST

Pleistocene dune limestone is exposed in cliffs typically 60 feet to 100 feet high but in places as much as 200 feet that have been formed by wave action (Plate II fig 3) In the vicinity of Thunder Point (fig 1) these cliffs occur for a short distance but from 2½ miles east of the Hopkins River almost to Childers Cove they are continuous The only rock exposed is dune limestone except that Miocene marine limestone is present at the base of the cliffs east of section 15A Parish of Mepunga This stretch of coast follows generally the trend of a partially denuded swale passing to the east-south-east the slope of the dune surface being towards the sea until the coastline cuts diagonally across the axis of the dune after which the

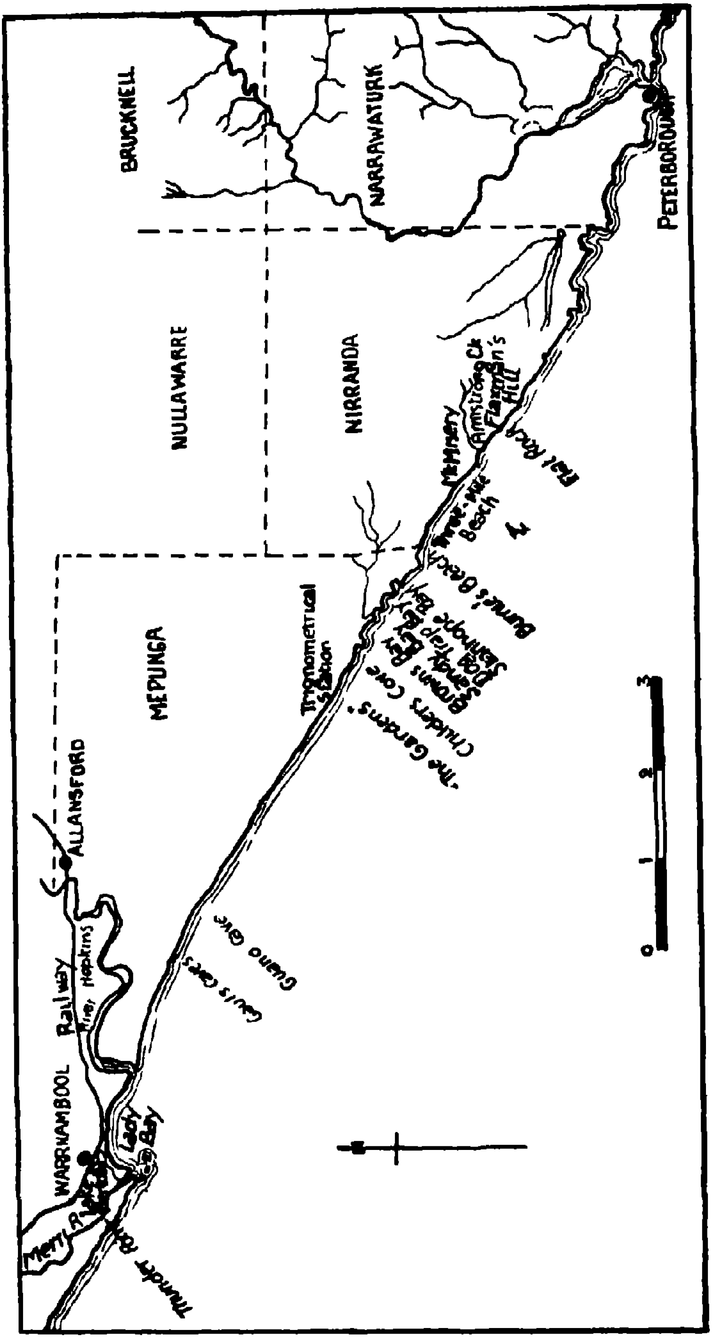

Fig 1—Locality plan of coast between Warrnambool and Peterborough
Scale Two miles = 1 inch

slope is landwards Three soil layers are generally present and except where they have been indurated by secondary deposition these soil layers have an important effect on the erosion of the cliffs They are readily disintegrated by wind and water and so hasten the breaking down of the cliff face

At Warrnambool there are some five lines of dunes while between the Hopkins River and Lake Gillear there appear to be only two lines but these are very high From that point eastwards there is only one line of dunes No fossils were found in the dune limestone along the coastal section except on a small headland less than 100 yards west of Guano Cave (fig 1) The relationships of the rocks concerned are shown in fig 2 The fossiliferous calcareous bed shown in the figure is about 10 feet thick and its base is roughly 5 feet above high tide level It rests on the Miocene marine limestone and is covered by a fossiliferous soil layer which in turn is covered by 60 to 70 feet of dune limestone in the cliff face The 10 ft bed consists of calcareous sand mixed with siliceous grit Numerous marine shells occur in this bed including cf *Turbo* (*Subninella*) *undulatus* (Martyn 1784) and cf *Neothais textiliosa* (Lamarck 1822) These determinations were kindly made by Dr F A Singleton The sand gravel and fossils are firmly cemented by secondary calcium carbonate In places numerous flat pebbles of dune rock—typical beach pebbles—are found in the bed which is very localized

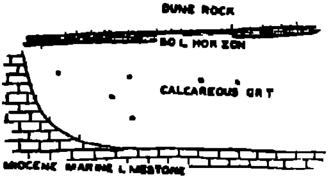

FIG 2—Fossiliferous calcareous grit, surmounted by a soil horizon at base of dune series just west of Guano Cave The fossiliferous bed is about 10 feet thick and contains pebbles of dune rock

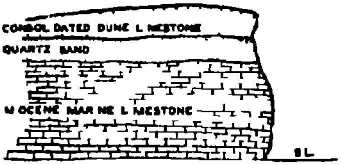

FIG 3—Sea cliff on headland forming east side of Stanhope Bay The cliff is approximately 120 feet high, consisting of about 80 feet of Miocene marine limestone about 20 feet of fine quartz sand and about 20 feet of hard dune rock

The indurated soil layer above this fossiliferous bed contains numerous land shells and also a number of marine shells and bryozoan zoaria many of which are also preserved as casts and moulds The unusual mixture of land and marine fossils in this bed may be explained as a beach or sea floor which has become a land surface and later covered by dune sand

The inclusion of flat pebbles of dune limestone in the fossiliferous bed indicates that there were probably earlier dunes to seaward of the present ones The author s earlier paper (1943) described how the dune rock exists below the present sea level in the Warrnambool district

MIOCENE MARINE LIMESTONE COAST

This type of coast from Peterborough eastwards to Pebble Point has been described by Baker (1943 1944) From Childers Cove to Peterborough it is characterized by vertical cliffs of fairly homogeneous yellow marine limestone with a dune limestone cover The bedding of the marine limestone is generally horizontal but at the eastern end of Three Mile Beach (Plate II, fig 1) it dips 4 degrees west Fossils are common but poorly preserved, except for some of the more robust forms *Lovenia forbesi* (T Woods) *Ditrupa* (massed in distinctive bands) and a small brachiopod are common

The homogeneous character of the limestone results in more even erosion of the cliffs than is seen at Port Campbell, where clays and limestones occur. From Childers Cove to Peterborough the sides of the rock stacks and cliff faces are almost vertical, slight projections resulting where more resistant bands occur. Along the dune limestone coast from Warrnambool to Childers Cove, apart from the general disintegration of the cliff face, erosion is accompanied by the breaking off of huge irregular blocks of rock, whereas along the marine limestone coast east of Childers Cove high vertical columns of horizontally-bedded strata break away. The difference is due, in the first case, to soil layers in the dune limestone, disconformities due to the building of other dunes on a planated surface formed on older dunes, and to cross-bedding; in the second case, to the general horizontality of the bedding and vertical jointing. Fissures (up to 6 feet across) are common along the tops of the cliffs in both types of coast; some are obviously old, temporary equilibrium of the stresses operating on the cliff face having been established. These fissures have assisted in the formation of caves, which are of fairly frequent occurrence. These latter have been formed by solution along the fissures, and by mechanical action where they have been exposed to wave attack. The inlets along the marine limestone coast are nearly always rectangular in outline with pocket beaches at their landward ends. This characteristic is due to erosion along major joint planes, which results also in the parallel orientation of rock stacks and islands with the sides of the inlets (cf. Baker, 1943).

Geological Succession

MARINE LIMESTONE AND DUNE LIMESTONE

Usually there is a well-defined soil layer between these two formations. The dune limestone immediately above the soil layer is often coarser than that higher up in the dune The gentle undulating character of the soil layer at the surface of contact indicates that the old land surface was as physiographically mature as the present surface of the Miocene limestone further inland. At Broken Bay crystalline calcite up to 3 inches thick occurs in crevices of the dune limestone near its base.

MARINE LIMESTONE AND SANDS

In the Parishes of Mepunga, Nullawarre, and Nirranda (fig. 1), there are large quantities of fine-grained siliceous sand, which in the field occurrence look bluish. This sand is even-grained, unlike the sub-basaltic deposits at Warrnambool which often have coarse gravel in them and, still more frequently, clay. On macroscopic examination the bluish sands appear to consist entirely of silica, whereas the Warrnambool sub-basaltic deposits have large quantities of granitic felspar present. The sand area supports a characteristic plant assemblage known locally as " The Heath Patch." The sand is generally in the form of low dunes (now fixed by vegetation), this being especially the case in the vicinity of the coast. Well-defined dunes about 25 feet high occur near the trigonometrical station shown in fig. 1. The sands are comparable in many ways with those of the dunes of the Brighton-Frankston area described by Whincup (1944).

The stratigraphical position of these sands is shown in a cliff section on the east side of Stanhope Bay (fig. 3), where a thickness of about 20 feet of them is interbedded between marine limestone and the dune limestone. The sands are probably a residue from the denudation of the Miocene land surface. If the dune limestone is Pleistocene, then they are perhaps Pliocene in age. However, the sands on the open plain behind the dune rock (where they have not been covered and preserved by later rocks) may be Pliocene to Holocene in age.

Evidences of Change of Sea-level

Much of the evidence for changes of sea-level requires further critical study and correlation, but there are clear indications of a relative eustatic fall in sea-level of the order of 15 feet. Evidence of this has been cited by Coulson (1940), Edwards (1941), Baker (1944, p. 79), and the writer (Gill, 1943). Further evidence is to be seen in some ot the beach formations along the Miocene marine limestone coast. At Flat Rock (on the coast south of the west border of section 50A, Parish of Nirranda), there is a long and well-defined beach ridge (Plate II., fig. 1); another can be seen on Burnie's Beach. Typical high marine limestone cliffs, obviously formed by the action of the sea, and with sea caves at intervals along the coast, are now never reached by the sea. The coast here is straight and open Between these old sea cliffs and the present strand line is a wide sand flat with a beach ridge on its seaward edge.

At the east end of Three Mile Beach there is an old shore platform 12 to 13 feet above the present shore platform Plate II, fig 2, is a frontal view taken from the present shore platform at low tide This platform and the old one are in homogeneous Miocene marine limestone The old platform is covered with vegetated talus except at the edge, where it is swept by storm waves The east end of the Three Mile Beach sections the shore platform, and shows boulders and some shells on its surface.

Shell beds, like those at Warrnambool, have been recently mapped at Port Fairy, about 17 miles further west They are extensive, and the numerous shells in them are in such a condition as to indicate that they were laid down in quiet waters.

Volcanic Julia Percy Island lies off the coast in this area. A wave-cut platform about 15 feet above the present sea-level has been described by the McCoy Society's Expedition there (1937).

Around the coast of Australia there are many indubitable evidences of change of sea-level. Professor Richards (1939) has summarized these for Eastern Australia.

Climatological Inferences

The blue quartzose sands which constitute ancient dunes along the coast behind the high lithified calcareous dunes must have been formed at a time of more arid climate than the present, for they are now covered with a well-defined soil layer and strong vegetative cover. The rainfall at that time was too low to cause enough growth to anchor the sand, and so it blew up into dunes; but the rainfall is now sufficient to support a forest The sands are not simply coastal dunes, but stretch inland for some miles Hubbard and Wilder (1930), in discussing the validity of the indicators of ancient climates, remark, "Wind-blown sand usually suggests a region that is or has been arid" Hills (1940) suggests that the sand ridges of the Moorabbin-Highett district were formed during periods of relative aridity.

There are present also in the area under discussion, evidences of a relatively wetter climate. The parish plans show swampy areas across most of the plain between Allansford and Peterborough, but a large number of these have now been drained or have naturally dried out. Some Western District lakes have dried up within living memory. Apparently, at one time there was a chain of swamps and small lakes across this country, and in many of these beds of peat were formed. There are a large number of deposits of peat in the district (e.g., in sections 32c, 47, 48, 50A, Parish of Nirranda), that at Brucknell (Herman, 1913) being the best known. A windmill bore on section 50A, Parish of Nirranda), near Flat Rock, passed through 8 feet of peat and 7 feet of clay before reaching the Miocene marine limestone of the bedrock Ferguson (1920) maps peat in the Port Fairy area These deposits suggest that wetter conditions than at present prevailed in the past In discussing peat as a climatic indicator, Giles (1938) names ' abundant (though not excessive) and well distributed rainfall " as one of the conditions favourable to the formation of peat. However he quotes areas of relatively small rainfall where considerable deposits of peat occur (p 408) and appears to infer that the deposits were laid down under climatic conditions the same as the present The recent large climatic changes associated with the Ice Age need to be kept in mind

Thus it appears that in the area dealt with in this paper the climate has been both drier and wetter than it is now

Acknowledgments

Mr A Mathieson senr of Nullawarre has provided me with much interesting information concerning the district I wish to thank Mr R A Keble of the National Museum Melbourne for many opportunities of discussing Victorian coastal forms Mr W Barangwanath of the Victorian Geological Survey kindly made available information concerning peat at Brucknell

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Description of Plate

Plate II

Fig 1—View looking west along Three Mile Beach showing former sea cliff beach ridge &c

Fig 2—Showing former shore platform at east end of Three Mile Beach The photograph was taken at low tide from the present shore platform

Fig 3—Consolidated dune limestone cliffs a few hundred yards west of Guano Cave Note soil horizon behind figure This photograph was taken by Mr Alex Wilkins of Warrnambool

Port Fairy—Peterborough Coastline

1

2

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[Proc Roy Soc Victoria 58 (N S) Pts I II 1947]

Art V—*An Australian Record of the Foraminiferal Genus* Hantkenina

By W J PARR

[Read 12th July 1945]

The foraminiferal genus *Hantkenina* has not hitherto been recorded from Australia and in view of its proved value as an index fossil in other parts of the world its discovery in the Cape Otway district of Victoria in deposits the age of which has been uncertain is of special importance

The presence of *Hantkenina* in the Tertiary of Australia was first recognized in December 1944 when the writer found portion of a test in a sample of glauconitic clay from the Brown s Creek coastal section 8½ miles north west of Cape Otway This material had been collected by Dr F A Singleton of the Geology Department of the University of Melbourne during the course of field work upon which he has been engaged in the district over a number of years Subsequently the writer in company with Dr Singleton and his sons Messrs O I and P D Singleton visited the area and collected material from which more than 30 examples of *Hantkenina* have been obtained Eight of these specimens were from the Brown s Creek locality and the remainder are from Hamilton Creek about 6 miles east of Brown s Creek The specimens have most of their delicate spines intact and are not infilled their state of preservation being so perfect that there can be no doubt as to their being indigenous to the deposit in which they were found

Seven of the specimens from Brown s Creek are from a highly glauconitic bed containing numerous examples of the pelecypod *Notostrea* This rests on the glauconitic clay from which Dr Singleton s specimen was obtained An additional example was obtained by the writer from the clay The specimens from Hamilton Creek are all from the most southerly exposure of Tertiary on the creek where it occurs in the west bank about 400 yards north of the Great Ocean road With one exception the examples of *Hantkenina* from this locality are from the glauconitic clay which as at Brown s Creek underlies a highly glauconitic bed with abundant *Notostrea* The other specimen is from the *Notostrea* bed The glauconitic clay is the lowest fossiliferous bed exposed at each locality the underlying beds at Brown s Creek being covered by dune sand and those at Hamilton Creek being below the level of the creek

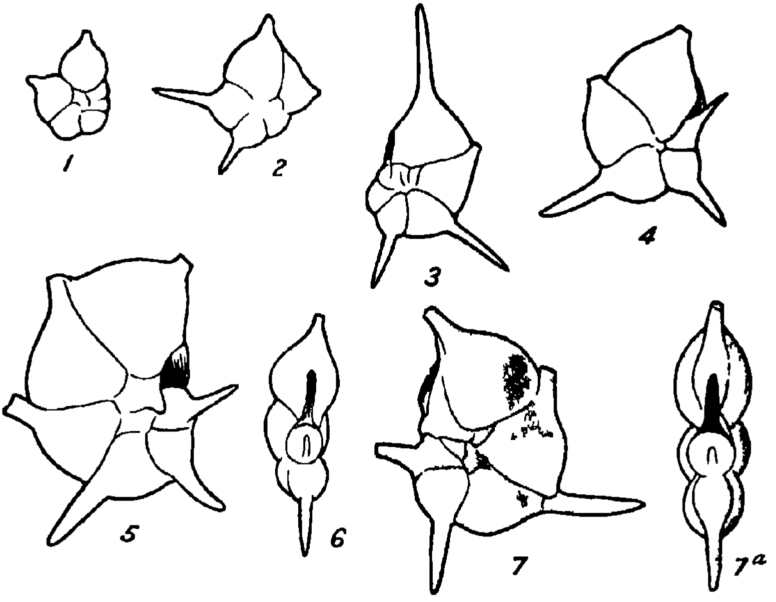
The foraminifera associated with *Hantkenina* at both localities are almost wholly perforate calcareous species very many of which are undescribed Those at Hamilton Creek include species of *Spiroplectammina Lenticulina Dentalina Nodosaria Vaginulina Lagena Fissurina Entosolenia Ellipsolagena Guttulina Globulina Glandulina Sigmomorphina Gumbelina Buliminа Bolivina Angulogerina Cassidulina Ellipsonodosaria Ellipsoidina Spirillina Heronallenia Alabamina Eponides Gyroidina Notorotalia Ceratobulimina Robertina Epistomina Anomalina Cibicides Chilostomella Pullenia Sphaeroidina Globigerina Nonionella* and *Astrononion* At Brown's Creek all of these genera with the exception of *Entosolenia Ellipsolagena Ellipsoidina Notorotalia* and *Sphaeroidina* also occur in addition to *Textularia Dorothia Quinqueloculina Spiroloculina Pyrgo*

Ramulina, *Virgulina*, *Uvigerina* and *Discorbis*. The Eocene form described by Cole (1927, p 22, pl 5, fig 12) under the name of *Nonion micrus* is also common at both localities. The foraminifera enable the *Hantkenina*-bearing beds at Brown's Creek to be correlated with those at Hamilton Creek, a conclusion which Dr Singleton has reached on other evidence.

The form of *Hantkenina* represented at Hamilton Creek and Brown's Creek is closely related to *H. alabamensis* Cushman from the Upper Eocene of U.S.A. It may be described as follows:—

HANTKENINA ALABAMENSIS Cushman subspecies *compressa* nov.

Test planospiral, compressed, adult whorl with five or six moderately inflated chambers, each as long as broad, furnished with a long hollow peripheral spine which is situated at the front end of the chamber and directed forward; wall finely punctate, surface granulated on the early chambers, later smooth; aperture in the centre of the face of the last formed chamber, an elongate, comparatively narrow opening widening at the lower end, which is extended forward on each side as a narrow flange.



Hantkenina alabamensis [illegible] *compressa* [illegible] Figs 1–6, Hamilton Creek; Figs 7, 7a, [illegible] Brown's Creek. All figures × [illegible]

Dimensions of holotype.—Diameter with spines 1 mm, without spines 0.6 mm, thickness 0.2 mm.

Holotype from Brown's Creek, collected by the writer.

This form differs from previously described *Hantkeninae* in the considerably greater compression of the test and in the shape of the aperture. Occasional examples of *H. alabamensis* showing similar characters are found in material from U.S.A. in which *H. alabamensis* is common, but they are not typical of the species as it occurs there. Figures are given to show the range of variation in the Victorian form. It will be noted that some of the specimens in the early stages resemble *H mexicana* and *H longispina* in having the outer end of the chamber drawn out and terminating in a centrally placed radial spine These two species are not known to occur above the lower half of the Bartonian

The species of the *H alabamensis* group range through the Upper Eocene (Bartonian) and there are records of the occurrence of several from the Lower Oligocene (Lattorfian) These are by Howe (1928 p 13) from U S A Rey (1938) from Morocco and Finlay and Marwick (1940 p 93) from New Zealand In view of this the beds in Victoria in which *Hantkenina* has been found are either Upper Eocene or Lower Oligocene in age The presence of specimens of the Victorian form showing in the early stages some of the characters of *H mexicana* and *H longispina* suggests that it is of a rather more primitive type than *H alabamensis* With this in mind and having regard to the fact that the majority of the records of the *H alabamensis* group are from the Upper Eocene it appears probable that the beds from which the Victoria specimens were obtained are Upper Eocene in age

The writer is indebted to Dr Singleton for making available the material which led to the discovery of *Hantkenina* in the Tertiary of Victoria He also thanks Dr M F Glaessner for his advice and helpful criticism in the preparation of this note

The holotype and other figured specimens will be deposited in the collection of the Geology Department of the University of Melbourne

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[Proc Roy Soc Victoria 58 (N S) Pts I-II 1947]

Art VI —*Evaporation and Storage Changes in River Catchment Areas with Special Reference to the Goulburn River above Eildon Reservoir*

By V G ANDERSON F R I C

[Read 12th August 1945]

Abstract

Annual evaporation losses and storage changes in the river catchment areas of Victoria are discussed in relation to their effects upon the composition of natural waters The river gauging and rainfall records of the Goulburn River catchment area and other typical areas were used as a basis for the investigation Precipitation is the only source of water in the Goulburn catchment which was selected to illustrate a useful method of approach Underground leakage from this area is impossible The composition of water from the Goulburn River is compared with waters from two adjoining areas—the Yarra River catchment which is nearer the coast and the more distant Murray River catchment

Relationships between river flow and rainfall under assumed ideal conditions are contrasted with actual relationships disclosed on studying the river gaugings and rainfall records No continuous run off is yielded by Victorian catchment areas unless the annual rainfall is at least 13 inches but the threshold rainfall of some rivers is 20 inches or more River flow is diminished by direct evaporation and by the transpiration of plants Evaporation may continue after water is absorbed in the ground but ultimately some absorbed water reaches the river system after being temporarily retained in the area Seasonal gains and losses of underground water are always to be expected and also there may be a net gain or loss over the whole year Water carried over from year to year transforms an otherwise simple problem of interpreting results of river data into one of considerable complexity

As the discussion is confined to areas free from underground leakage observed discrepancies between river flow and precipitation must be attributed to the combined effects of evaporation and storage changes No direct methods are available for measuring evaporation nor of ascertaining whether in a particular year the gauged flow was increased or decreased by storage changes However gains and losses can be eliminated by averaging long period records in which case mean evaporation is the difference between the mean precipitation and mean discharge for the period But the problem of estimating evaporation and storage changes in a particular year has hitherto remained unsolved The arguments presented in this paper are centred around the problem of eliminating from the annual gauged flow of a river uncertainties caused by the volume of water retained or released in the above mentioned manner

The data for the Goulburn area consists of 29 pairs of annual gaugings and rainfall records The period of observations although comparatively short includes at least one complete major cycle of storage and depletion When the ungrouped data are statistically correlated the coefficient (r = +0 9464) indicates strong association between discharge and precipitation The relationship may be expressed by a linear equation R_e = 0 8626P 16 31 the standard error of estimation is 2 57 Corresponding results for other catchment areas in Victoria are tabulated for purposes of comparison Evaporation and storage changes can be estimated when in addition to precipitation and the gauged discharge for a particular year the computed flow is also known Evaporation estimated from the difference between precipitation and computed flow increases as precipitation rises Enhanced opportunities for evaporation at wet surfaces in years of higher rainfall may account for this regressional increase Storage changes are estimated from the difference between the computed flow and the gauged discharge Compound bar charts and cumulative diagrams are employed to illustrate the effects of rainfall variations upon storage changes in the Goulburn area The whole period may be divided into six sub periods on the basis of these diagrams Two phases of absorption or recharge are clearly recognizable as well as two others during which stored water was being released from the catchment area An important conclusion is that for seven successive years during which correlation was exceptionally strong (r = +0 999) climatic and other conditions were such that storage changes would not have been likely to occur estimates of evaporation based on the data for this sub period confirm those deduced from the data for the whole period The results also indicate the possibility that the total upstream storage capacity of the Goulburn catchment area can be estimated Although the investigation was carried out primarily in connection with the composition of natural waters the results are of wider interest, and suggest new fields of inquiry

Introduction

GENERAL OUTLINE

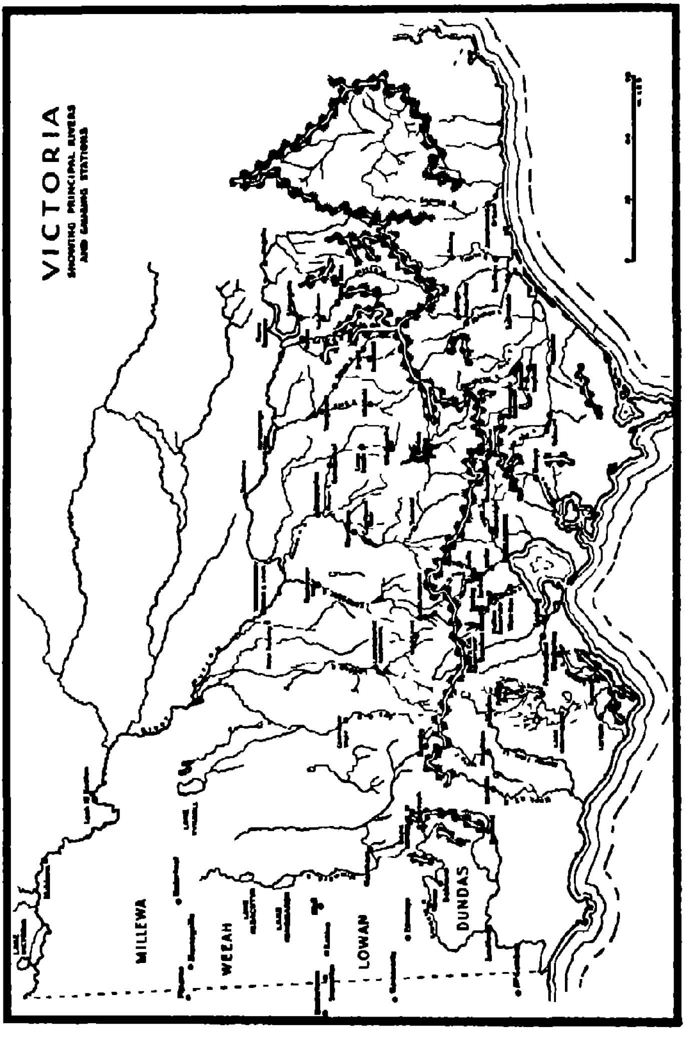
This study is an integral part of an investigation on relationships between the composition of natural waters and environmental conditions within the catchment areas from which the waters are derived Evaporation and underground storage changes are the factors particularly under review in the present paper estimates being based upon the results of river gaugings and rainfall observations published by the State Rivers and Water Supply Commission of Victoria(1) The catchment of the Goulburn River above Eildon in north eastern Victoria is used to illustrate a general method of approach but a summary of the characteristics of other Victorian areas is included for purposes of comparison The catchments investigated unless otherwise indicated are based upon impermeable bedrock and each derives its water exclusively from meteoric sources within its own area

The author has already shown that the principal sources of mineral impurities in Australian waters are (*a*) the soluble products of rock weathering and (*b*) air borne oceanic salts brought down in rain water(2) The amount of contamination from the products of rock weathering depends upon the geological environment but the proportion of oceanic salts brought to a catchment is in general independent of rock composition or structure and is chiefly governed by geographical position

Desiccated spray from sea water is blown inland for great distances and in significant quantities the movement of suspended particles even reaching the proportions of transcontinental dust storms in reverse Red dust from Central Australia is sometimes driven over the Tasman Sea Not so well known is the fact that salt from the coast is carried by high winds to the interior of the Continent The particles being soluble in water and almost invisible their presence is often unsuspected unless rain water is chemically examined but probably every important catchment area in Australia is more or less influenced by this unseen transfer of oceanic salts

The relatively low concentrations of sea salts in rain water may at first sight, make them seem unimportant but concentrations are greatly increased by natural evaporation and transpiration after the water reaches the ground Records of river gaugings and rainfall show that in Victoria the average proportion of water removed by evaporation varies from 50 per cent in exceptionally efficient catchments to 95 per cent in useful but inefficient areas In semi arid regions the unevaporated residue which still contains the soluble oceanic salts is sometimes less than 1 per cent of the rainfall In addition to the effects of rock weathering and the occurrence of air borne salts in the rain water a third factor evaporation is thus equally important in determining the composition of natural waters in Australia and a stage has now been reached when an improved method for estimating it is urgently needed

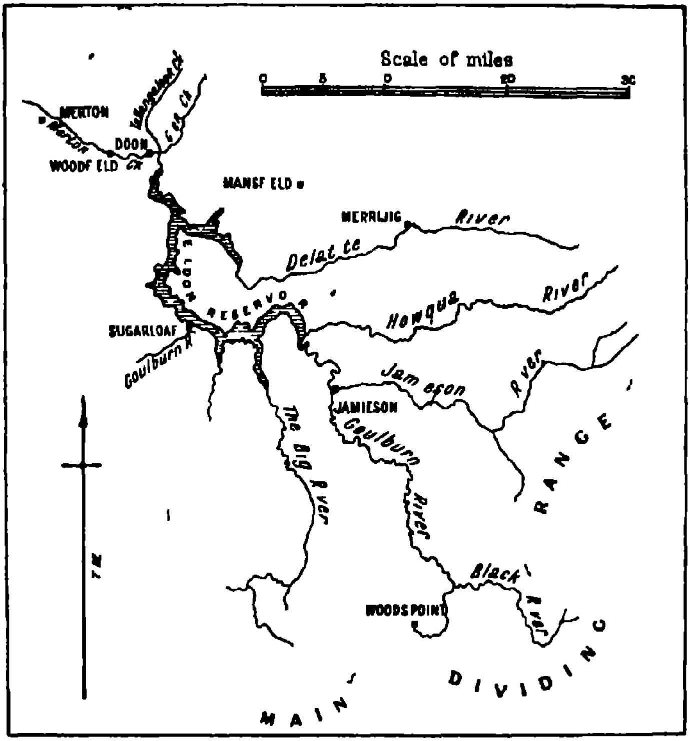
Storage also above or below the surface may affect the final composition of a natural water otherwise than by providing opportunities for evaporation Chemical changes of a secondary character such as the biochemical oxidation of sulphur compounds, can occur during storage under aerobic conditions, but the anaerobic reduction of sulphates is a common occurrence during the underground storage or transfer of natural waters. Sulphates originally derived from oceanic sources can be completely removed from ground water in this way. Again, during the temporary storage underground, natural "softening" of a water sometimes takes place, calcium and magnesium being more or less completely replaced by chemically equivalent amounts of sodium or potassium. For various reasons, therefore, it is desirable to know how much of the rainfall in a particular year is temporarily stored in the ground, or alternatively, how much previously stored water is released to augment the flow of the river.



THE GOULBURN CATCHMENT AREA

DESCRIPTION

Situated on the northern slopes of the Main Divide almost in the centre of the Eastern Highlands the Goulburn catchment area is one of the most efficient in Victoria The present capacity of the Eildon Reservoir is 306 000 acre feet but extensions are being planned The geological map shows that the area of 1 500 square miles above Eildon consists almost entirely of slates and sandstones of Carboniferous Devonian Silurian and Ordovician ages There are also small isolated areas of igneous and granitic rocks Maps published in the Reports of the Interstate Conference on Artesian Waters (1912 1928)(8) show that this catchment is part of an area in which no artesian basin of any material size can exist Leakage of underground water into or out of the catchment is negligible and influxes of magmatic and other types of juvenile water are extremely improbable Apart from annual precipitation and rain water previously stored in the ground no other source of water is available



Map of Goulburn River Catchment Area above Eildon Reservoir

The main axis of the catchment is approximately 90 miles from the coast In relation to its distance from the sea it occupies an intermediate position between two areas which have been described previously(2) viz the Yarra River basin and the valley of the Upper Murray River

COMPOSITION OF RIVER WATER

The waters of the above-mentioned rivers differ from each other considerably, but all have remained remarkably constant in composition for a long period Typical results of analysis and other data are given in Table I

TABLE I—COMPARISON OF WATERS FROM THE YARRA, GOULBURN, AND MURRAY RIVER CATCHMENT AREAS

CATCHMENT AREA DATA	YARRA RIVER AT WARRANDYTE	GOULBURN RIVER AT EILDON WEIR	UPPER MURRAY RIVER AT TOCUMWAL
Area (square miles)	972	1 600	10 234
Mean Annual Precipitation (inches)	44 61	49 59	33 19
Mean Annual Discharge (inches)	13 89	17 80 } 27 years	9 40
Mean Annual Evaporation (inches)	30 72	21 79	23 79
Percentage of Water Evaporated	68 9	65 0	71 7
CHLORIDES (Cl) IN RAIN WATER			
Milligrams per litre	4 4	2 9	1 0
Pounds per acre per annum	44 4	26 0	7 5
COMPOSITION OF RIVER WATER			
MILLIGRAMS PER LITRE			
Cl	15 3	6 2	3 4
SO_4	1 6	1 9	1 3
HCO_3	14 3	27 8	23 0
NO_3	0 4	Nil	Trace
Ca	2 8	3 7	3 9
Mg	1 9	2 8	2 1
Na	8 5	4 6	2 4
K	1 7	1 5	1 0

POUNDS PER ACRE OF CATCHMENT AREA (ANNUALLY)

—	YARRA RIVER		GOULBURN RIVER		MURRAY RIVER	
	Derived from Sea Water	Not Derived from Sea Water	Derived from Sea Water	Not Derived from Sea Water	Derived from Sea Water	Not Derived from Sea Water
Cl	48 1		26 3		7 2	
SO_4	5 0		3 60	4 5	1 0	1 8
HCO_3	0 4	44 6		118 0		48 9
NO_3		1 2				
Ca	1 0	7 8	0 6	15 1	0 2	8 1
Mg	3 2	2 8	1 8	10 1	0 5	5 0
Na	26 7		14 6	6 0	4 0	1 1
K	1 0	4 3	0 55	5 8	0 1	2 0

Preliminary Discussion on Catchment Area Relationships

PRECIPITATION AND DISCHARGE

Precipitation on Victorian catchment areas is estimated from daily observations at a number of selected localities, the records from different stations being weighted to ensure that each locality is represented proportionately in respect of its area The annual flows are computed from daily readings of river levels at specially selected gauging stations Methods of procedure are described in River Gaugings (1905) and other reports

Under ideal conditions river discharge should equal precipitation The annual gauged discharges (R) if plotted against the corresponding values for precipititation (P) might be expected to lie evenly along a straight line having its origin at the intersection of the R and P axes, and inclined at an angle of 45 degrees to the P axis (Figure 1 A–A^1) In practice, however, the annual discharge of a river is invariably less than precipitation, and the plotted values are often found to be widely dispersed in the form of a scatter diagram, such as that illustrated in Figure 1

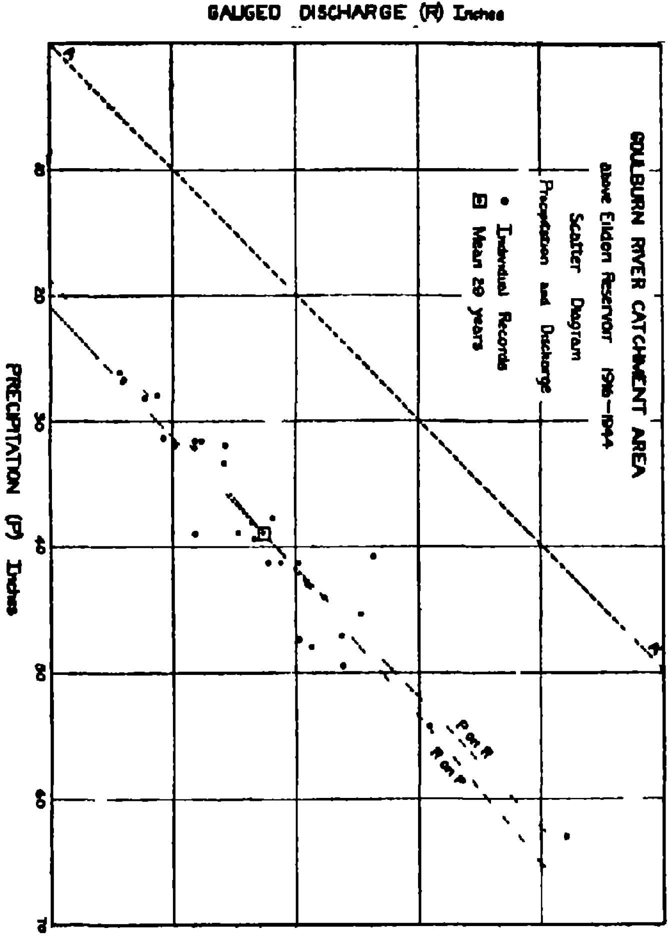


Fig 1

Precipitation is clearly the ultimate source of the discharged water but the precise nature of the relationship between P and R is not immediately apparent from an inspection of the scatter diagram One of the principal objects of this paper is to isolate the obscuring factors, especially evaporation and storage fluctuations, and then as far as possible to estimate the magnitude of each of them This can only be done against a background provided by the catchment area equation and with due regard to statistical principles

Evaporation and Transpiration

A substantial part of the rain-water falling on a catchment area is either directly evaporated or utilized by vegetation, and, in consequence, never reaches the river system In the following discussion "evaporation" on a catchment area is intended to include transpiration It is known that unless the mean annual precipitation exceeds a certain critical value, which may be called the threshold value, no continuous flow is yielded by catchment areas, although heavy rainstorms, or the release of ground water, may provide some run-off even in the driest years The threshold values of Victorian catchments known to be enclosed by, and based upon impervious bedrock, range from 13 to 22 inches Equality of precipitation and evaporation at the threshold value affords a basis for estimating the mean amount of evaporation which occurs under dry conditions, when the mean annual rainfall is just sufficient to cause incipient river flow

STORAGE

Much of the rain water falling upon a catchment area soaks into the ground and becomes woven into the fabric of the vegetative and soil systems including the underlying weathered rock material before being released again in the form of seepages and springs which finally drain into the river or its tributaries Surface run off from higher parts of a catchment area may be absorbed into the ground at lower elevations Some water may remain in the ground for several years before actually reaching the river If the water is accessible to the atmosphere, and to the roots of trees or other plants, losses by evaporation and transpiration may occur during storage In the subsequent discussions, the use of the term " storage " is not restricted to ground water below the water table, but includes soil moisture and all other water whether temporarily immobilized or moving towards the water table, or to the outlets of the drainage system as a whole

Seasonal variations in the volume of stored water are always to be expected, but, during a series of wet years the net amount of water stored in a catchment tends to increase at the expense of river flow On the other hand, net depletion occurs in dry years, river flow being augmented Variations in flow caused by daily and seasonal differences in the intensity or incidence of rainfall are automatically smoothed out in making the annual summations but net changes for the annual period are not eliminated, and are responsible for part of the scatter illustrated in Figure 1, and they considerably add to the difficulty of interpretation

THE CATCHMENT AREA EQUATION

River flow is the greatly reduced residue from annual precipitation Some water falling upon a river basin may be permanently lost by underground leakage to adjoining or distant areas a large proportion is always lost by evaporation River flow, in a particular year, may be diminished if water is temporarily retained in the area, or it may be supplemented by the release of water previously stored within the catchment

An equation expressing relationships between precipitation (P), the gauged annual discharge (R), evaporation (E), and other factors influencing river flow, may be stated as follows —

$$P = R + E + U + A \qquad 1,$$

where U is the water lost by underground leakage, and A is the net increment to accumulated storage The same symbol (A) is used, with changed sign, to represent a depletion of reserves previously stored within a catchment area

The following discussion is simplified by confining it exclusively to catchment areas from which leakage is impossible, hence the equation may be written in the following form —

$$P = R + E + A \qquad 2$$

The practical value of this equation would be enhanced if direct measurements of either E or A could be made, but only in exceptional cases is this possible However the effects of storage variations may be eliminated by averaging long-period records of discharge and precipitation, gains in wet years being then offset by equivalent losses in other years The equation may, therefore, be re stated in a form which can be used for estimating the mean annual evaporation from a river basin —

$$P_{mean} = R_{mean} + E_{mean} \qquad 3$$

Hitherto, the best available method for estimating evaporation was based upon equation 3 Such estimates, however, correspond only to a particular value of P, viz P_{mean} and afford no information about the amount of evaporation occuring when precipitation is above or below its mean value It will be shown later that, by appropriate methods it is possible to develop an equation for computing values of river flow which are not only free from the disturbing effects of storage variations but are applicable to any corresponding value of precipitation within the observed range Computed flows from which storage variations have been eliminated are conveniently designated by the symbol R_c to distinguish them from the gauge discharge (R), the relation between R_c and R being as follows —

$$R_c = R + A = P - E \qquad 4$$

The general equation is then simplified to—

$$P = R_c + E \qquad 5$$

On investigating the precipitation and discharge records of 25 catchment areas in Victoria the author has found that a simple linear relationship exists between R_c and P which may be expressed as follows —

$$R_c = a + bP \qquad 6$$

The constants a and b may be calculated from long term records of river gaugings and precipitation and the equation used for estimating R_c and E for any value of P within the range covered by the data The fact that linear equations satisfactorily express precipitation-discharge relationships of catchment areas in Victoria considerably reduces the labour involved in making computations of this kind It is conceivable, however, that for some catchment areas the use of polynomial equations may be necessary

Statistical Treatment

THE GOULBURN DATA

The relatively small number of records available for statistical examination consists of 29 pairs of official observations of rainfall and river gaugings the latter being adjusted for volumes released or impounded, and for evaporation in the reservoir The frequency curve of annual precipitation is very flat, but it discloses a normal distribution during the period of 1916-1944 Estimates of skewness indicate only a slight degree in the rainfall records, and a rather more pronounced degree in the discharge data, but, for practical purposes, both distributions may be regarded as sufficiently symmetrical to provide a basis for treatment by ordinary statistical methods

Some doubt may exist as to whether observations over a period of 29 years are sufficiently representative to eliminate systematic errors due to long-term cycles of charge and recharge In general, it is desirable to use at least 40 pairs of annual observations, unless it can be shown that a shorter period includes at least one complete cycle of storage changes, or there is a reasonable expectation that the volume of water stored in the catchment area was substantially the same at the end of the period as at its commencement As a long drought period immediately preceded the year 1916, it may be inferred that the Goulburn area was in the same depleted condition prior to 1916 as it was at the end of 1944. Notwithstanding, therefore, the relative shortness of the period of observations, the wide ranges of precipitation and discharge in this catchment area and the certainty that leakage can be excluded make it particularly suitable for illustrating a method of approach which is applicable to the majority of other river basins in Victoria.

CORRELATION

An appropriate method of treatment is to correlate discharge data with annual precipitation over all individual pairs, regarding complexities due to changes in underground storage and sundry random errors as a group of uncontrollable deviations. The correlation co-efficient (r) and the constants of the equation relating discharge and precipitation are computed and the standard error of estimation is calculated. It is then possible against the background of the catchment area equation to deduce some quite definite information about the relationship between precipitation and evaporation. Net annual gains and losses in underground storage are estimated as the difference between the computed and gauged discharges. This method may require modification and elaboration in the light of additional information, but even in its present form it greatly assists in clarifying the various issues and relationships.

The catchment area data with relevant extensions and derivations are ranked on the basis of annual precipitation and set out in Table II.

TABLE II.—THE GOULBURN RIVER CATCHMENT AREA ABOVE EILDON WEIR

Correlation of Precipitation and Discharge Data (1916–1944) showing Computed Evaporation and Estimated Storage Changes (in Inches)

1	2	3	4	5	6	7	
Year	Precipitation (P)	Discharge (R)	Difference (P−R)	Computed Discharge (R_c)	Computed Evaporation (L)	Estimated Storage Changes (R_c—R)	
						Storage	Depletion
1938	26.2	5.6	20.6	6.3	19.9	0.7	
1940	26.7	6.0	20.7	6.7	20.0	0.7	
1944	28.1	8.6	19.5	7.9	20.2		0.7
1937	28.3	7.7	20.6	8.1	20.2	0.4	
1922	31.4	9.3	22.1	10.8	20.6	1.5	
1925	31.6	12.4	19.2	10.9	20.7		1.5
1927	31.6	11.9	19.7	10.9	20.7		1.0
1919	32.0	10.1	21.9	11.3	20.7	1.2	
1943	32.0	14.4	17.6	11.3	20.7		3.1
1929	32.1	11.6	20.5	11.4	20.7		0.2
1933	33.4	14.3	19.1	12.5	20.9		1.8
1932	36.9	18.2	18.7	15.5	21.4		2.7
1936	38.2	16.5	21.7	16.6	21.6	0.1	
1930	38.9	15.4	23.5	17.2	21.7	1.8	
1941	39.1	11.9	27.2	17.4	21.7	5.5	
1934	39.5	16.6	22.9	17.8	21.7	1.2	
1931	40.8	26.4	14.4	18.9	21.9		7.5
1926	41.3	20.2	21.1	19.3	22.0		0.9
1920	41.4	17.9	23.5	19.4	22.0	1.5	
1921	41.4	18.8	22.6	19.4	22.0	0.6	
1918	43.0	21.0	22.0	20.8	22.2		0.2
1935	44.1	22.2	21.9	21.7	22.4		0.5
1942	45.3	25.2	20.1	22.8	22.5		2.4
1923	47.1	23.7	23.4	24.3	22.8	0.6	
1924	47.4	20.3	27.1	24.6	22.8	4.3	
1928	48.0	21.2	26.8	25.1	22.9	3.9	
1916	49.5	23.9	25.6	26.4	23.1	2.5	
1939	54.3	30.6	23.7	30.5	23.8		0.1
1917	63.0	42.0	21.0	38.0	25.0		4.0
Total	1,132.6	503.9	628.7				
Mean	39.06	17.38	21.68				
Standard Deviation	8.74	7.96	2.64				

Correlation Coefficient (r) = 0.9464
Constants of estimating equation ($R_c = a + bP$)
a = −16.31
b = 0.8626
Standard Error of Estimation 2.57

THE REGRESSION OF RIVER DISCHARGE ON PRECIPITATION

The co efficient of correlation ($r = +0{\cdot}9464$) indicates a very close association between annual precipitation and river flow over the range of the available observations Although the association is strong the estimating equation accounting approximately for 90 per cent of the total variance of the discharge data a decision had to be made respecting the basis on which the regression should be calculated that is to say whether P or R was to be regarded as the independent variable In any case the two possible regression lines are not widely divergent (see Fig 1) but as river flow in this catchment is known to depend primarily upon water from meteoric sources the choice of precipitation as the independent variable is appropriate

The constants for the Goulburn catchment area are as follows —
$a = -16{\cdot}31$ $b = 0{\cdot}8626$ b represents the rate of change of river flow per unit of precipitation in the absence of random deviations Expressed graphically b corresponds to the slope of the straight line indicating the regression of R_c on P while a specifies the point of origin on the R axis R_c may be regarded as the volume of river flow which in any year would be directly caused by precipitation in that year if there were no storage changes or other random deviations In the known absence of leakage the constants a and b are related to and are to be regarded as corrections for the amount of evaporation which occurs in the catchment The ratio $\frac{0 - a}{b} = 18{\cdot}91$ indicates the point ($R_c = 0$) at which the regression line intersects the P axis and therefore specifies the computed mean threshold precipitation below which all of the rainfall would be evaporated leaving no surplus for river flow A correction for any additional loss by evaporation of rainfall in excess of the threshold value is made by multiplying by $1 - b$ The equation for the Goulburn River catchment may be expressed in the following alternative form in which R_c is estimated by multiplying the regression co efficient (b) by the difference between the mean threshold value and total precipitation —

$$R_c = 0{\cdot}8626\,(P - 18{\cdot}91) \qquad 7$$

It is one of the basic assumptions of the present method of approach that dependable estimates of R_c can be made even when losses by evaporation and fluctuations in storage are known to occur from year to year Individual values of the gauged discharges do not appear in the estimating equation but the whole of the available data is used in the statistical procedure for computing the constants of the equation In this respect R_c is hardly less important than the mean discharge and possesses the additional advantage that it can be computed for any observed annual precipitation whereas R_{mean} corresponds only to the mean precipitation for the whole period

It will be observed by reference to Table III (column 8) for Victorian catchment areas the constant (b) is always significantly less than unity

THE REGRESSION OF EVAPORATION ON PRECIPITATION

The difference between precipitation and the gauged discharge may be regarded as a crude estimate of evaporation in a catchment area during a particular year but the effects of storage changes must be eliminated to obtain the true evaporation The most direct method for estimating E is, therefore to subtract the computed discharge (R_c) from precipitation (P)

TABLE III.—TYPICAL CATCHMENT AREAS IN VICTORIA

Correlation Data

1	2	3	4	5	6	7	8		9	10
Catchment Area	Gauging Station	Area (Square Miles)	Period of Observations (Years)	Mean Annual Precipitation (P) (Inches)	Mean Annual Discharge (R) (Inches)	Correlation Coefficient (r) +	Constants of Estimating Equation ($R_0 = a + bP$)		Standard Error of Estimation	Computed Threshold Precipitation $\frac{o - a}{b}$
							a −	b +		
(1) NORTH OF DIVIDE										
(a) *North Eastern*										
Goulburn	Eildon Weir	1 500	29	39·06	17·38	0·948	16·31	0·8636	2 57	18·91
Murray	Jingellic	2,520	52	37·54	13 86	0·896	10·11	0·6386	2·66	15·83
Mitta	Tallangatta	1 990	50	37·44	10·88	0·879	10·31	0·5660	2·38	18·22
Ovens	Wangaratta*	2,090	50	42 86	10·75	0·818	10 70	0·5005	3·39	21·38
Broken	Goorambat*	730	50	31 68	5·65	0·829	10 75	0·5092	2·27	21·11
Kiewa	Kiewa	434	51	50·37	23 77	0·649	9·97	0·6691	3 58	14·90
(b) *Central*										
Coliban	Malmsbury	112	50	35·08	8·96	0 833	10·58	0·6571	2·64	18·99
(c) *North Western*										
Loddon	Laanecoorie	1,592	46	24 35	2·20	0·819	4·23	0·2637	2 86	16·04
Avoca	Coonooer	1,029	41	19 46	1·05	0 839	2·31	0·1725	0 49	13·40
(2) SOUTH OF DIVIDE										
(a) *South Eastern*										
Yarra	Warrandyte	972	23	44 61	13·88	0·864	12·11	0·5827	2·18	20·78
Tambo	Bruthen	1,040	19	27 84	3·83	0·830	5·73	0 3433	1·37	16·70
(b) *Central*										
Maribyrnong	Keilor	550	26	28·12	3·00	0·849	6·43	0·3355	1·16	19·16
(c) *Western*										
Barwon	Pollocksford	1,425	15	25·33	1·91	0·923	3·37	0·2087	0·37	16·15
Woady Yallock	Pitfield	122	15	26·40	3·30	0·696	8·82	0·4591	1·61	19·21
Glenelg	Sandford	3,320	20	25 85	3·40	0·817	9·20	0·4876	1·25	18·87
Glenelg	Balmoral*	606	45	25·93	3·56	0·893	6·36	0·3830	1·84	16·61

* The possibility of slight leakage cannot be excluded.

Applying this method to the Goulburn catchment area for different values of P, the following typical results are obtained —

TABLE IV—GOULBURN RIVER—CATCHMENT

The Regression of Evaporation on Precipitation

Precipitation (P)	Computed Discharge (R_c)	Evaporation (E)
18.9 (threshold)	0.0	18.9
26.2 (lowest)	6.3	19.9
39.1 (mean)	17.4	21.7
52.4 (relatively high)	28.9	23.5

Evaporation increases progressively with precipitation and discharge but its range of variation is much less This indication that evaporation in the catchment area is insensitive to changes in precipitation is of importance when considering the accuracy with which evaporation can be estimated There is a significant correlation ($r = +0.423$) between precipitation and crude evaporation estimated as the difference between P and R The relationship between P and E in the Goulburn area may be expressed as follows —

$$E = 0.137 P + 16.3$$

At Melbourne total evaporation from a free water surface is usually less in wet than in dry years A significant inverse correlation ($r = -0.403$) was found between the rainfall and total evaporation at Melbourne when the records covering a period of 68 years (1877-1944) were investigated But the converse is true of evapo-transpiration in Victorian catchments This regressional increase of evaporation on precipitation in catchment areas is difficult to explain except by assuming that additional opportunities for evaporation occur in years of higher rainfall

It will already have been noticed that the regression co-efficient of discharge on precipitation ($b = 0.863$) accounts only for 86.3 per cent of the rainfall even after making due allowance for the loss by evaporation which is known to occur before any of the water is available for river flow Permanent leakage from the catchment would explain the inadequacy of the regression co-efficient to account for the whole of the rainfall in excess of the threshold value but leakage from this catchment is impossible owing to the impermeable nature of the underlying and enclosing rocks On the other hand a regressional increase in evaporation is by no means unlikely because in Central Victoria the mean threshold value corresponds with an evaporation equal only to one half of the total annual evaporation from a free water surface The threshold evaporation does not, therefore exhaust the evaporative possibilities of the local climate Opportunities for evaporation at wet surfaces might be expected to be greater during years of abundant rainfall compared with the necessarily limited opportunities available in dry years Transpirational losses are also greater in good years, when vegetative growth is heavier

The regression of evaporation on precipitation is compared with that of discharge in Figure 2.

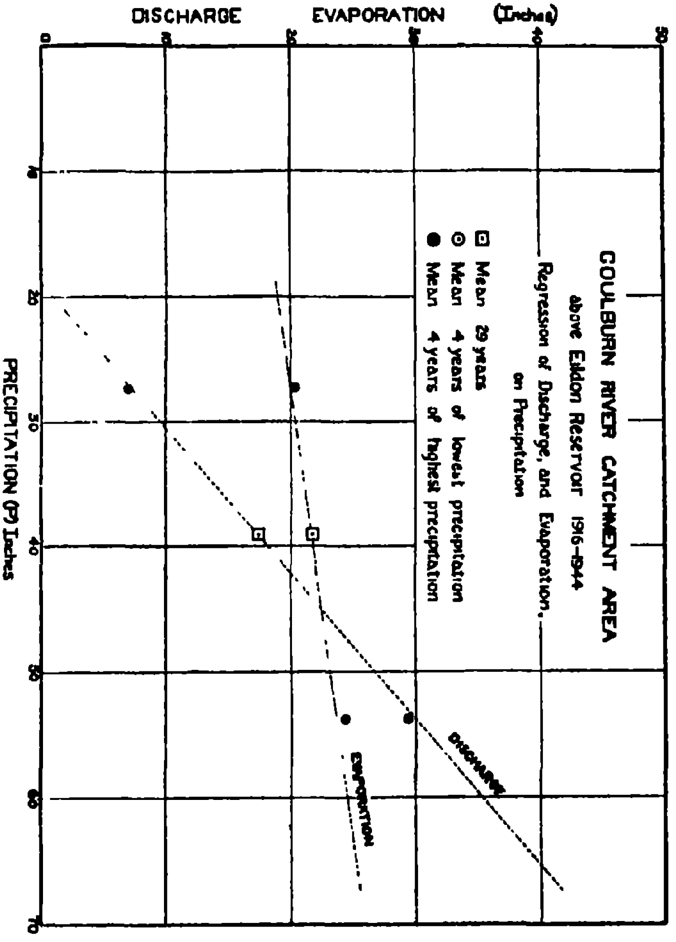


FIG. 2.

THE RESIDUAL VARIANCE.

Changes in ground-water storage can sometimes be estimated by observing the water levels of wells and lakes. Measurements have been made at Blue Lake, Mt. Gambier (S.A.), where the surrounding country is comparatively flat, and the porous Tertiary limestone permits rapid readjustment of the lake level to changes in the ground-water table. It seems doubtful, however, whether any analogous method could be usefully applied in the mountainous catchment area of the Upper Goulburn River, but estimates of storage changes can be made by comparing the gauged discharge (R) of the river with the computed discharged (R_c). The difference between R and R_c is regarded as an estimate of net storage or depletion. As a first approximation, it may be accepted that increments and decrements of stored water are responsible for the whole of the difference between R and R_0 Two assumptions are involved—the first is that if no storage changes occurred, the relationship between precipitation and discharge would be strictly a linear one the second is that deviations due to storage changes if they do occur will be normally distributed about the regression line The reliability of the estimate obtained by difference in this way depends of course upon the degree of accuracy with which (R_e) can be estimated as well as upon the reliability of the river gaugings

The assumption that storage changes are responsible for the residual variance is sufficiently well founded to warrant its adoption as a working hypothesis pending further investigation In the catchment of the Avoca River where storage changes are known to be small residual variance is relatively low It was also exceptionally low in the Goulburn area for seven successive years when precipitation was not high enough to recharge this catchment which had become depleted during three preceding dry years A comparison of the characteristics of the Avoca and Goulburn catchment areas is of considerable interest in this connexion

In the mountainous areas of Eastern Victoria climatic and physiographic conditions are favourable to storage changes which normally manifest themselves in large perennial streams Opposite conditions prevail in north western Victoria particularly in the catchment of the Avoca River where the terrain is relatively flat and the mean annual rainfall is only 19 46 inches (maximum 28 0) Depletion can occur only from a previously charged catchment area and a depleted catchment can only be recharged during periods of relatively high rainfall It is unlikely that in the Avoca catchment area precipitation is sufficient even in wet years to allow any appreciable surplus of stored water to be carried over from year to year after evaporative demands have been met Net storage changes are therefore at a minimum although not completely absent and the river is semi intermittent in character Over a period of 41 years the standard deviation of R was relatively low (0 90) compared with that for the Goulburn catchment area (7 96) In these circumstances poor correlation seemed inevitable but the association between precipitation and discharge is strong owing to a corresponding decrease in residual variance the standard error of R for the Avoca area being 0 49 which is less than one fifth of that computed from the Goulburn River records for 29 years (2 57)

Included in the Goulburn records there is a period of seven years during which the catchment area remained in a depleted condition after an earlier dry period Precipitation in the preceding three years was relatively low although river flow was comparatively high indicating a phase of depletion Precipitation during the sub period under review (1934 1940) was variable but the average (36 76) was below the mean for 29 years (39 06), and obviously insufficient to recharge the depleted catchment area Correlation of precipitation with discharge was unusually high (r +0 999) the linear relationship being represented by the following equation —

$$R_e = 0\ 892\ P - 17\ 7$$

The standard error of estimation is 0 40 When this equation is used to predict the discharge of the Goulburn River corresponding to the mean precipitation for 29 years (39 06 inches) the estimate (17 1 inches) is not significantly different from the mean discharge (17 4 inches) for 29 years The predicted threshold value is 19 9 inches compared with 18 9 inches the value predicted by the equation computed from the data for 29 years Strong correlation alone does not necessarily indicate the absence of net storage changes because it is conceivable that during the sub period the area may have been either gaining or losing water at a uniform annual rate. However, the close correspondence between the constants of the equation for the sub-period, and those computed for the period of 29 years, practically excludes both possibilities. Although a slight storage trend is indicated when the results for seven years are aligned with those for the whole period, they are consistent with the view that the shorter period was one in which there was no significant increase or decrease in storage. Obviously, the whole problem is simplified when periods substantially free from storage changes are available as a basis for estimating evaporation.

General Discussion of Results

Storage and Depletionary Trends.

Annual variations in precipitation, river flow, estimated evaporation, and storage changes, for the period under review, are illustrated in a group of compound bar-charts (fig. 3).

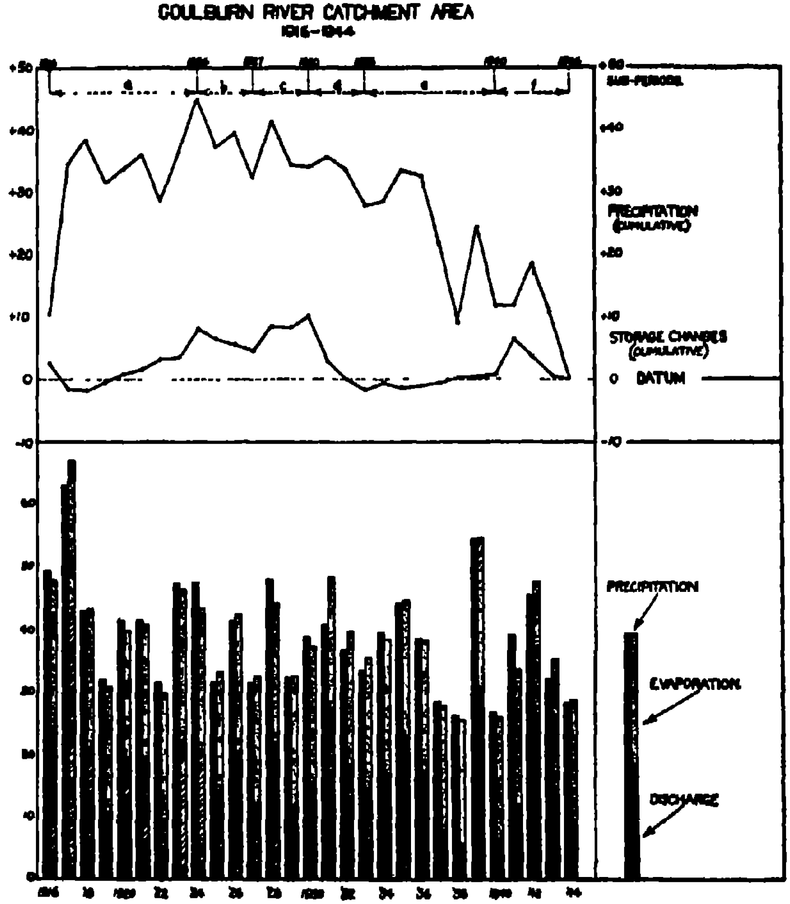


Fig. 3.

This diagram shows whether apart from seasonal variations water was stored in, or released from the catchment area during a particular year Conclusions indicated are consistent with some well established facts concerning the storage of water in catchment areas and explain some apparent anomalies in discharge phenomena They also suggest several new fields of inquiry

The general tendencies discernible in this diagram may be summarized as follows —

(*a*) Water is stored in a catchment area during cycles of high average rainfall An occasional dry year does not always alter the general trend unless a considerable amount of water has already been accumulated in the catchment area

(*b*) Depletion of water from a charged catchment occurs during periods of low average rainfall A single wet year does not necessarily alter a general depletionary trend

(*c*) The amount of stored water tends to remain constant from year to year when a period of depletion is soon followed by a further dry period More than one wet year may be required to alter this tendency which along with others is more clearly illustrated in the cumulative diagram (fig 3)

There are also indications yet to be confirmed that floods and other catastrophic phenomena facilitate the release of water from charged catchments possibly by eroding new seepage channels or by removing natural barriers which would otherwise retard the escape of water

Modified mass or cumulative diagrams despite obvious disadvantages are particularly useful for illustrating storage changes in catchment areas The datum of the cumulative rainfall diagram is the mean annual precipitation for the whole period deviations from the mean being plotted cumulatively Estimated gains and losses of stored water are also plotted cumulatively in a second diagram On comparing the two charts several periods of release and recharge as well as the relatively constant period are recognizable together with corresponding variations in rainfall On the basis of these diagrams the period under review may be divided into the six sub periods shown in Table IV

TABLE IV—GOULBURN CATCHMENT AREA 1916–1944

Sub periods of Release and Recharge

Sub periods	Number of Years	[illegible]	Mean Precipitation (Inches)	Mean Discharge [illegible]	Storage Changes during Sub periods	
					Inches	Acre feet Whole Area
(a) 1916–24		Recharge	44	[illegible]	8	[illegible]
(*b*) 1925–2[illegible]	3	Release	4[illegible]	14 8	3 3	200 000
(c) 1928–3[illegible]	[illegible]	Recharge	[illegible]	1[illegible] 1		440 000
(d) 1931–33	[illegible]	Release	37	1[illegible] 6	1 [illegible]	960 000
(e) 1934–4[illegible]		Approximately constant		[illegible]		[illegible]
(*f*) 1941–44	4	Variable	36 1	1[illegible]	−0 8	64 000
1916–44	29		[illegible] 06	17 38		

APPARENT ANOMALIES.

Some apparent anomalies may be explained with the aid of the diagrams. For example, during three years commencing in 1928, (c) the average discharge (16·1 inches) of the Goulburn area was lower than in the following three years (19·6 inches), notwithstanding the higher average rainfall (39·7 inches) during the former period, compared with the rainfall (37·0 inches) of period (d). To explain this anomaly in terms of evaporation changes would involve the highly improbable assumption that the average annual loss by evaporation in one period was 6·2 inches greater than in the other. The average difference in evaporation estimated from the regression of E on P was only 0·4 inch. It has already been shown that evaporation is much less variable than either precipitation or discharge. The explanation indicated by these diagrams is that during sub-period (c) appreciable amounts of water were retained in the catchment at the expense of river flow, while in the three following years of diminishing rainfall the flow of the river was augmented by water released from the catchment. This is not an isolated case, but is quite typical of many examples which could be cited from other catchment areas in Victoria.

Sub-period (e) during which, as previously described, only slight changes in stored water occurred, except possibly for seasonal variations, is also typical of the behaviour of other river catchments during periods of low average rain following an earlier dry period. Apparently a state of equilibrium was reached, beyond which further augmentation of river flow by ground-water was impossible.

EVAPORATION DURING STORAGE.

Evaporation and storage conditions in catchment areas are closely related, and both have important effects upon the quality of river waters. The effects of evaporation can be recognized and estimated by observing changes in the concentration of chlorides originally present in the rain-water. In the Eastern Highlands, springs and seepages feeding the mountain-tract tributaries of river systems, yield waters containing very low concentrations of chlorides. A marked increase is usually observed before the streams emerge into larger river valleys. Progressive increases in chlorides are found in tributaries which enter the main stream from open plains. It is often supposed that the higher chlorinities of the lower reaches of a river are due to the ocean, but the same tendency is noticeable in some rivers north of the Main Divide, and which flow away from the coastline. Greater opportunities for evaporation in the open plains account for this increase in salinity.

It is well known that the dry-season flow of rivers is often more saline than the flow in wet seasons. But the author has observed that the chlorinities of some river waters, in Victoria, are definitely lower during dry seasons. The waters of the Yarra River, and of other Victorian streams, contain a higher proportion of chlorides in winter than in summer. After prolonged droughts, the Yarra water is consistently lower in dissolved solids. Storage conditions explain this unexpected effect on river waters in Eastern Victoria. Ground-water temporarily stored deep below the surface in mountainous areas is partly protected from atmospheric evaporation and transpiration. But in flat poorly-drained country, particularly when most of the underground-water remains near the surface within reach of the roots of trees, appreciable evaporation occurs during the storage period. Release of ground-water from protected parts of elevated catchment areas continues throughout the dry season, and then constitutes the principal source of river flow The preponderance of water which has been protected from evaporation, thus reduces the chlorinity of the river water in dry periods because flow from the lower and less efficient part of the catchment then becomes negligible, or entirely ceases In the following wet season water stored in lower parts of the area which had become more or less concentrated by evaporation during the dry season is carried to the main river in the flow of intermittent tributaries thereby making an appreciable addition to the salinity of the river water

UPSTREAM STORAGE CAPACITY

The rate at which water can be retained or released during an annual period appears to be limited but unidirectional trends often persist for many years, in extreme cases for 20 years before a reversal occurs on completion of a rainfall cycle In the Goulburn area during the period under review six successive years between 1919 and 1924 was the longest sub period in which water was absorbed depletion occurred during the following three years Storage reached a maximum value in 1930 of 10 2 inches above datum After a period of rapid depletion the value fell to 1 8 inches below datum and remained almost constant for another seven years The difference between the maximum and minimum values (12 inches) is equivalent to 960 000 acre feet for the whole catchment and it may be regarded as a preliminary estimate of the upstream storage capacity of the Goulburn area during the period under review It is interesting to note that this volume is rather more than three times the present capacity of the Eildon Reservoir A period of minimum storage was clearly reached between 1934 and 1940 but the catchment may not have been fully charged in 1930 Observations covering a longer period would be necessary before this question can be answered Records extending for 50 years are available for the Mitta and Upper Murray River catchments where the upstream storage capacities indicated are considerably higher Rainfall distribution and other physical conditions would obviously affect the total storage capacity of a catchment area and these differ from those prevailing in the Goulburn area The possibility of being able to make even approximate estimates of the upstream storage capacities of catchment areas opens up an interesting field for further investigation

Acknowledgments

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Art. VII.—*The Victorian Earth Tremor of 3rd November,* 1944.

By A. J. GASKIN, M.Sc.

[Read 12th July, 1945]

A strong earth tremor occurred in Victoria on November 3rd, 1944. In the Melbourne area, it was felt between five and six minutes after midnight of November 2nd. The tremor was generally described as beginning with an audible phase, which varied, according to the locality, from a loud crack to a low rumbling sound, followed or accompanied by one or more phases of more or less intense vibration lasting from one to four seconds.

The shock was recorded by the seismograph at Melbourne Observatory. The period of vibration was not great enough to be measurable on the record. The velocity of travel of the light beam in the photographic recorder being comparatively high, the peaks of the waves on the trace have been underexposed so that the maximum amplitude cannot be determined with certainty. It was probably not much more than 2 mm., corresponding to a ground movement of 8μ at the Observatory. The following measurements were obtained from the record:—

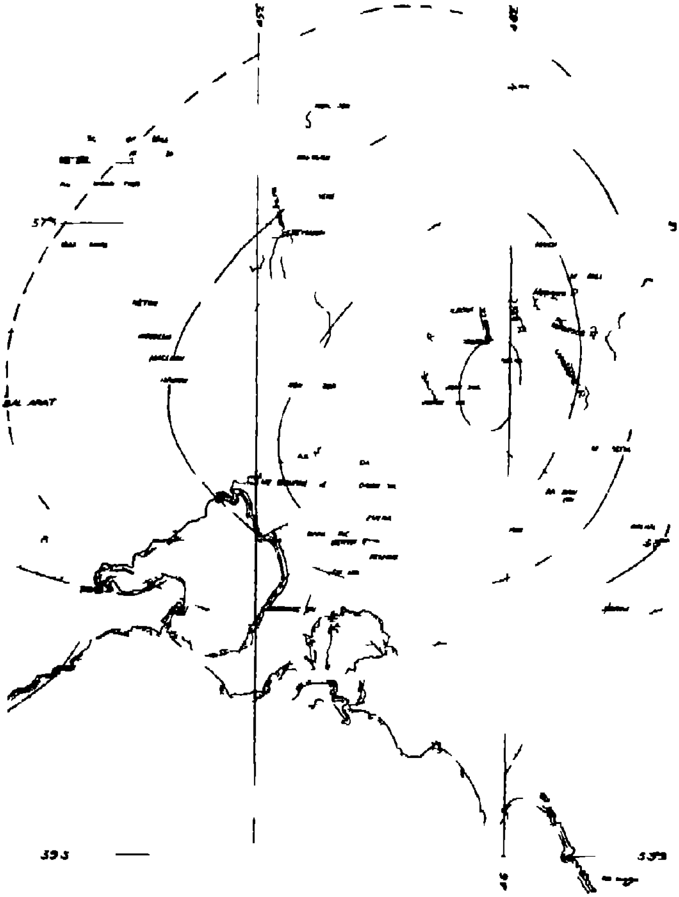
i	14 h 05 m. 43 s.
i	14 h 05 m. 46 s.
i	14 h 05 m 49 s.
i	14 h. 05 m 53 s.
M	14 h 05 m. 57 s.
m	14 h. 06 m 03 s.
m	14 h. 06 m. 08 s.
F	14 h 06 m. 30 s.

(Universal time.)

The distance of the epicentre from Melbourne as estimated from the P–M interval is of the order of 45 miles, which is nearly twice the distance of the Mornington epicentre from Melbourne (Holmes, 1933). This accounts in part for the smaller amplitude of the 1944 tremor as recorded in Melbourne. The over-all intensity of the 1944 tremor was, however, considerably less than that of the 1932 shock, minor destructive effects in the epicentral area of the 1944 shock being comparatively rare.

Following a public request for information, about 100 reports concerning the tremor were received from observers in the Melbourne area, and about 75 from country observers. Intensities on the modified Mercalli scale (Wood and Neumann, 1931) were assessed from these reports, and mapped in an attempt to determine the epicentre of the shock. Because of the small degree of variability of intensity shown between reports from widely separated areas, this procedure did not give a particularly accurate map of the isoseismals, but when the nature and duration of the phases of the tremor (described in most reports) were taken into account, a more satisfactory approximation to the epicentre was obtained (see text fig.). Reports from localities within the 4 isoseismals describe the audible phase as a loud crack, with a very short interval between it and the subsequent phase of movement. The latter was felt as a very rapid jolting vibration of from one to two seconds' duration. With increasing distance from the epicentral region, the preliminary audible phase was reported to become lower in pitch, dying away to a dull rumble in localities near the 3 isoseismal. In most districts outside the 3 isoseismal, the tremor produced a slower, more rhythmic, ground movement, unaccompanied by an audible phase.

Although the maximum reported intensity of the tremor was little more than 4 allowance must be made for the fact that the main epicentral region is situated in uninhabited mountainous country near the Cerberean Ranges a district from which no information could be obtained It is probable however that the maximum intensity of the tremor was nowhere greater than 4 5 and the shock appears to have been of a multiple focus type due to shallow depth fault movements associated with a NE SW stress line



Isoseists of the Victorian Earth Tremor of November 3rd 1944
(Outermost broken isoseism represents limit of detection of shock)

The suggestion of a multiple focus effect is based on the presence of the local epicentres near Healesville and Mt Dandenong Their positions on the map are based on the various aspects of the reports received from these districts One aspect of the reports that of the direction from which the audible phase appeared to come although often found to be an unreliable factor in seismic work gave reasonable evidence in this case as the directions reported, with very few exceptions pointed to the two local epicentral areas

At a point close to the line joining these two epicentres, two distinct audible phases were reported, the second being almost simultaneous with the ground movement phase of the first.

The assumption that the fault movement occurred at a relatively shallow depth is based on the sharp high-pitched nature of the audible phase in localities near the epicentres. Further evidence suggesting that the shock was connected with more than one focus is provided by the fact that it was felt over a considerable area (nearly 10,000 sq. miles), with no very great variation in actual intensity, although the epicentral areas were sharply defined by the character and time spacing of the phases. Blake (1941) has indicated that this type of shock is characteristic of simultaneous shallow-depth faulting along several inter-related lines in a stress zone.

The isoseismal map of the tremor (p. 67) shows that the three epicentral areas occur along a N.E.-S.W. line, which when produced to the S.W. joins the line of the Beaumaris monocline, and further S.W. the line of the Curlewis fault. It seems probable, therefore, that this line represents the strike of a fault or the trend of a stress zone in which minor faults are at present developing. Such a fault line would represent the north-western limit of the north-east south-west set of faults which are prominently developed in South Gippsland.

It is apparent from the map (p. 67) that the isoseismals are not only elongated along the direction of the stress zone containing the epicentres, but are asymmetrically distributed in directions at right angles to this zone. The shock waves have been transmitted to a much greater extent to the north-west of the stress zone than to the south-east. This effect is well shown on the map by the outermost (broken) isoseismal, which represents the limit of detection of the tremor. To the south-east of the epicentral area, this limiting isoseismal is very close to the Heath Hill and Bass River fault lines, so that it is almost certain that the relatively incompetent Jurassic and Tertiary sediments to the south-east of these faults have absorbed the rather high frequency shock-waves characterizing the epicentral areas to a much greater extent than have the rigid igneous and sedimentary rocks of the basement complex to the west and north-west of the epicentral zone.

The other point of interest concerning the geological aspects of the tremor is the fact that the epicentral areas are all within or near the boundaries of thick Devonian dacite flows, which overlie a basement complex of intrusive igneous rocks and older folded sediments. This observation suggests that it was only at points where the stress zone intersected massive lava flows that fracturing occurred sufficiently suddenly to give rise to the high frequency vibrations which characterize the districts that have been referred to above as epicentral areas.

There may be some significance in the fact that the tremor occurred in a period of intense drought following a succession of dry seasons, during which it is probable that the level of the water-table had been reduced more in the mountainous dacite areas than in the low-lying country surrounding them. The resultant change in the total weight of the dacite mountain masses may have been sufficient to generate the trigger force, which caused the sudden release of pre-existing tectonic stresses.

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[Proc Roy Soc Victoria 58 (N S) Pts I II 1947]

Art VIII—*Interference Fringes Produced by Scattering and Reflection*

By V D HOPPER

(Physics Department University of Melbourne)

[Read 8th November 1945]

Abstract

When a partly polished optical flat was placed face downwards on a standard flat and illuminated by a small bright white light source the pattern corresponding to the colours of thick plates was observed encompassing the image of the source When the top surface of the standard flat was aluminized the pattern was much more intense A new phenomenon occurred when the pair of plates was illuminated by light from a mercury lamp which passed through a narrow slit the single pattern giving place to two separate patterns whose intersections gave the locus of the pattern observed with white light When the scattering surface was made semi reflecting the double set of patterns became sharper one set being localized in the plane of the scattering surface, the other in planes corresponding to the position of the Newton ring pattern formed by multiple reflections Various experiments are described for studying these patterns It is concluded that all three systems of fringes are produced by multiple reflections between the two reflecting surfaces the assumption of Stokes that the colours of thick plates could only be produced by light passing and repassing the same particle being unnecessary It is considered that the pattern corresponding to the colours of thick plates is produced by the summation of the intensities of the light from a pair of separate patterns of the simpler Newton ring type one set being produced by light scattered by the top surface and then suffering multiple reflections between the surfaces before reaching the observer the other set being produced by light from the source suffering multiple reflections between the plates and finally being scattered by the scattering centres

Introduction

When a partly polished optical flat was placed on a standard flat and illuminated by an electric lamp it was noticed that an interference pattern which differed from the usual Newton ring pattern was observed surrounding the image of the source It was also observed that when a bright mercury lamp was used the pattern was resolvable into two systems of fringes of the Newton ring type the intersections of which produced a pattern similar to the first pattern observed The double set of interference patterns was sharper and more easily observed when the scattering surface was also made semi reflecting

A search of the literature revealed that Newton Young Stokes and others had been interested in interference patterns produced by surfaces capable of scattering light a phenomenon often discussed under the title The colours of thick plates So far as the author is aware the pair of patterns observed when a monochromatic light source was used has not previously been recorded The theory suggested to explain these latter patterns lead to a more general interpretation of the theory of the colours of thick plates so it is proposed to summarize the conclusions reached by some of the previous workers to describe the experiments that were carried out to obtain the additional system of fringes and to discuss an explanation for them and for the colours of thick plates

Earlier Experimental Work on the Colours of Thick Plates

Newton (1) in the fourth part of his second book of Optics described the following experiment. A white opaque card, pierced with a small hole, was placed at right angles to the optic axis of a concave glass mirror which had been quick-silvered at the back. The hole was at the centre of curvature of the mirror and the apparatus was arranged so that sunlight passing through a hole in a window shutter of a darkened room passed also through the hole in the opaque card and fell perpendicularly on to the mirror. A set of coloured rings was observed on the card encompassing the hole, and Newton attributed them to light scattered on entering the glass and then regularly reflected and refracted. He applied his theory of fits to account for the fringes.

In 1755 The Duke of Chaulnes (2) produced similar fringes by substituting in place of the glass mirror a metallic speculum in front of which he placed a plate of tarnished mica. The distance between the scattering surface and the reflecting surface could be readily varied, and he observed the variation in the diameter of the fringes with the distance between the surfaces. He also found that the brilliancy of the fringes produced by Newton's method was increased by breathing on the glass or by spreading over the surface a small quantity of milk and water, which on drying produced a good light scattering surface.

Quetelet (3) described a set of coloured bands that had been observed by Whewell when the image of a candle held near the eye was viewed by reflection in a plane mirror of silvered glass placed at a distance of some feet. Whewell and Quetelet found that it was an essential condition of success that the surface was not perfectly bright and to ensure the production of bands it was sufficient to breathe gently on the front surface of a cool mirror. Instead of vapour, which soon evaporated, Quetelet recommended a tarnish of grease.

Young (4), Herschel (5) and Stokes (6) applied the wave theory to account for the fringes observed by Newton They assumed that one stream of light was reflected by the mirror and then scattered at the surface, another stream was scattered at the surface and then reflected by the mirror. If the two portions of scattered light coincided in direction they were capable of interfering, bright bands occurring when the retardation of the two beams was an integral number of wave lengths. Stokes came to the conclusion that in order for the two streams of scattered light to be capable of interfering it was necessary that they should be scattered, in passing and repassing, by the same set of particles.

The experiments which will be described later using monochromatic light show that it is possible to observe two systems of fringes One set is produced by light scattered at one surface and then reflected; the other by light reflected between the plates and finally scattered. The intersections of these two patterns give the positions of the interference pattern studied under the title of the colours of thick plates.

The explanation for the double set of fringes observed when using monochromatic line also accounts for the single system that is observed with white light and this will be discussed later in this report.

Experimental Investigation

If one surface of a glass plate, capable of scattering, transmitting and reflecting light, is placed close to another surface which is capable of reflecting light, one might anticipate that there would be two ways in which an interference pattern could be produced. Consider Fig. 1(*a*) which represents two glass plates separated by a layer of air If surface A is capable of transmitting reflecting and scattering light and surface B of reflecting light an interference pattern would be observed by reflected light interfering with transmitted light the final beam being scattered by C Scattering centre C will be bright when viewed from any direction provided that

$$(n_1 + \tfrac{1}{2})\lambda = 2d \cos\theta \qquad 1$$

where θ is the angle of incidence of the light n_1 an integer and λ is the wavelength of the light employed

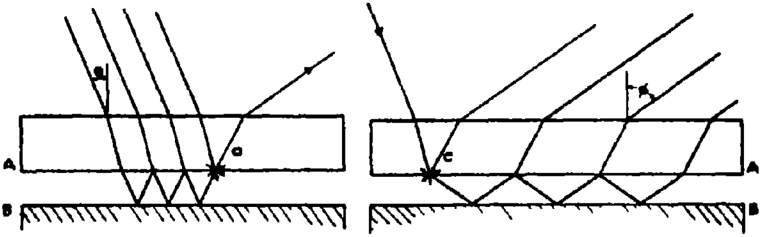

Fig 1 (*a*) Production of Set 1 pattern
(*b*) Production of Set 2 pattern

The system of fringes represented by formula (1) will be designated as Set 1 in this discussion

The other system of fringes which we shall call Set 2 is due to the interference of light that has been scattered from a scattering centre C and reflected by multiple reflections from the adjacent surfaces of the glass plates (see Fig 1(*b*)) Constructive interference occurs when observed at an angle ø provided

$$(n_2 + \tfrac{1}{2})\lambda = 2d \cos\phi \qquad 2$$

n_2 an integer

(Set 2 pattern could also be produced by scattering centres on the top surface of the top plate) The angle of incidence of the light will have no effect on this set of interference fringes other than to vary its brightness

It was found possible to clearly observe the two sets of interference patterns corresponding to Set 1 and Set 2 using the experimental arrangement of fig 2

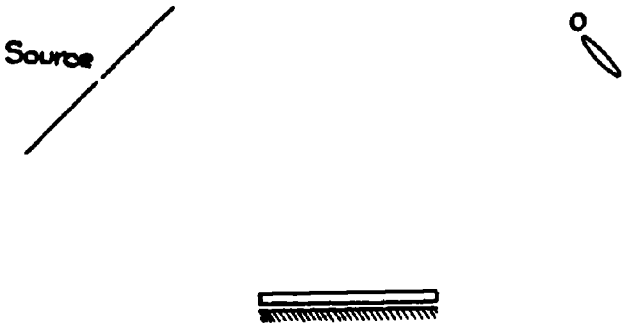

Fig 2.—Experimental arrangement for studying Set 1 and Set 2 interference patterns

For this experiment the two plates were optical flats about four inches in diameter. The lower surface of the top plate was made semi-reflecting (half aluminized), the top surface of the lower plate being reflecting (fully aluminized). The scattering points were scratches on the semi-aluminized surface, or were simply produced by spreading a thin smear of oil over the surface with a finger. The surface containing the scattering points was then placed parallel to the reflecting surface of the bottom plate. The flats were placed on the table and illuminated by a mercury lamp. The light from the source passed through a narrow slit (about 2 mm. wide) in a large black card, and the plates were arranged so that the scratched lines or smears of oil were normal to the direction of the light. On observing the reflected image at O it was observed that a double set of interference fringe patterns was visible, the one corresponding to Set 1 fringe pattern being localized in the plane of the surface of the half aluminized plate, whereas the other pattern (Set 2) was localized in a curved surface close to the scattering surface. This latter pattern corresponds to the position of the Newton ring pattern formed by multiple reflections, as given by Feussner (7) and discussed by Tolansky (8). (The double Newton ring pattern due to polarization observed by Tolansky is not resolvable under these conditions.) When one of the glass surfaces used in this experiment was slightly convex, the resultant ring pattern for Set 2 was localized in a regular curve one half before and one half behind the glass surfaces. For an air film the apparent distance D of the fringe from the surface of the plates is given by

$$D = \frac{d \sin \phi}{\alpha} \qquad \ldots\ldots\ \ldots\ldots\ldots\ldots 3.$$

where d is the separation of the plates at the point where the reflection of the light which produces the fringes occurs, α is the angle between the surfaces of the two plates at this point, and ϕ the angle of reflection of the light. Figure 3 illustrates the apparent location of the fringes observed at an angle ϕ to the normal.

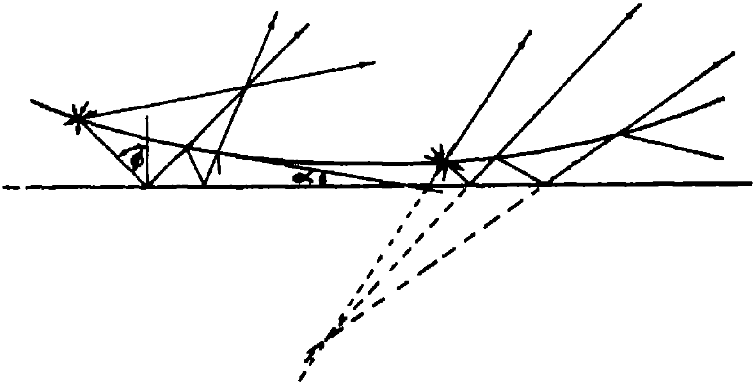

FIG. 3—Figure illustrating apparent location of fringes for a spherical surface with multiple reflections.

On studying the interference patterns produced, each set could be readily distinguished. When the observer moved, Set 2 pattern moved in the same manner as the usual Newton ring pattern, whereas Set 1 remained stationary relative to the plate. This confirms the interpretation that has been given.

Owing to the different location of the two sets of fringes produced in this manner it was difficult to obtain a clear photograph showing both sets together Plate III fig 1 gives the general effect of the combination of the two patterns The plates had been tilted so as to form a wedge angle, the two sets of fringes being then approximately straight lines inclined at slightly different angles The intersection of these systems is clearly seen as bright and dark bands running across the photograph and these will be discussed later

The double set of interference patterns could also be observed when the top surface was not made semi reflecting The patterns were then not as sharp the effect of half aluminizing the top plate being to increase the resolution of the fringes The double system of fringes could not be observed when white light was used and this would account for the fact that they had not been observed by the workers mentioned earlier in this report

A confirmation of the above interpretation of this double set of fringes was obtained by means of the following simple experiment

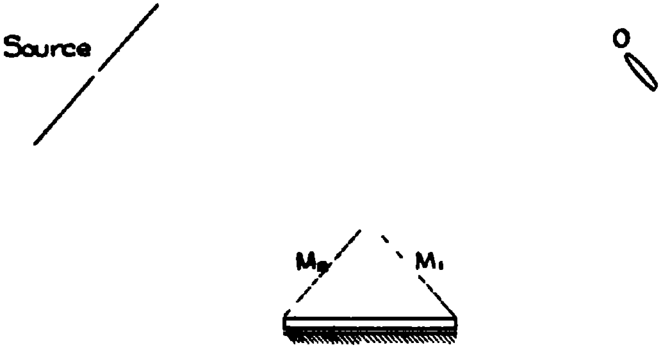

Fig 4—Frosted plate at M_1 produces pattern similar to Set 1 Frosted plate at M_2 produces pattern similar to Set 2 Filtered mercury green light with polaroid used

One surface of an optical flat was made semi reflecting and this was placed close to the surface of another flat that surface being a good reflector (fully aluminized) The surfaces were illuminated as in the earlier experiment the observer being at O A lightly frosted plate was placed at M_1 (fig 4) and an interference pattern was observed on the plate This pattern corresponded to the Set 1 system of fringes It was slightly enlarged owing to the distance of M_1 from the reflecting surfaces This pattern did not alter when the observer moved although it changed when the position of the source was altered When the frosted plate was moved from M_1 and placed at M_2 the pattern corresponding to Set 2 was observed (In taking these photographs a polaroid plate was placed before the lens of the camera and rotated until a sharp interference pattern was visible In this way the doublet system produced by the differential polarization phase change on reflection at a metallic surface is reduced to a single sharp system) The shape of this pattern varied with the position of the observer but not with the position of the source These two patterns corresponding to the frosted plate at M_1 and M_2 usually appeared distinctly different, and a typical example of such a pair of patterns is shown in Plate III fig 2 With the plate at M_2 the pattern was circular, a single interference colour practically covering the diameter of the plate, whereas with the plate at M_1 the line pattern was observed. Since the pattern with the frosted plate at M_2 corresponded exactly with the Set 2 pattern produce by scattered light at the surface of the plate one can infer that the interpretation given in fig. 1 (*b*) for Set 2 pattern is correct. For the frosted plate placed at M_2 and using surfaces free from scattering centres, fig. 1(*b*) could be modified slightly to interpret this result. Scattering centre C′ would be placed above the top plate at a position corresponding to the frosted plate A ray from this point making an angle of incidence of ϕ to the normal would produce a set of rays similar to those shown from. scattering centre C′ in fig 1(*b*). The condition for interference maxima would be given by

$$(n_2 + \epsilon_1)\lambda = 2d \cos \phi \quad \ldots\ldots\ldots\ldots\ldots\ldots 4.$$

where ϵ_1 represents the phase change at reflection from the surfaces. To simplify the discussion we will consider glass surfaces that are not aluminized giving ϵ_1 equal to $\frac{1}{2}$. That is, equation (4) becomes

$$(n_2 + \tfrac{1}{2})\lambda = 2d \cos \phi \quad \ldots\ldots\ \ldots\ldots\ldots\ldots 5.$$

If the interpretation for Set 2 pattern had been modified by omitting the ray that is scattered back into the glass from C′ towards the observer (fig. 1(*b*)), a system of fringes would be expected corresponding to

$$n_2\lambda = 2d \cos \phi \quad \ldots\ldots\ \ldots\ldots\ \ldots\ldots\ 6.$$

assuming again that the surfaces were not aluminized. This formula corresponds to the transmission interference fringe pattern for two parallel plates and it is noticed that it would be displaced one half fringe relative to a system corresponding to equation (5). The ratio of the intensities of the maxima and minima corresponding to equation (6) would be less than for equation (5), the theory being similar to that of patterns corresponding to transmitted and reflected Newton Ring patterns. This displacement of one half fringe between the pattern observed with the frosted plate at M_2 compared with the pattern corresponding to Set 2 is not observed either when the plates are aluminized or when the aluminium layers are removed. We may thus infer that the first ray scattered from C′ back into the glass and thence to the observer is necessary in the interpretation of the Set 2 pattern. It is also assumed that the ray in fig. 1 (*a*) which reaches the scattering centre C without a previous reflection and is scattered to the observer is required in the interpretation of Set 1 pattern. The study of the colours of thick plates confirms this assumption as will be shown later.

THE COLOURS OF THICK PLATES.

When, with the experimental arrangement shown in fig. 1, a white light source was used in place of the mercury lamp, a coloured line pattern was observed corresponding to the intersections of the two systems discussed above. When the plates were parallel, the lines were straight and approximately symmetrical about the reflected image. When one plate was tilted so that a wedge of air was formed, the distances between the lines was greatest where the air separation was least. With this experimental arrangement it was found difficult to obtain clear photographs of this pattern, so another method was used. A pair of plates of suitable size was inserted in place of the prism in a constant deviation spectrometer which had been adjusted for parallel light. One surface of one of the plates was aluminized, and one surface of the other plate carried scratches.

These scratches had been produced by sliding the plate over a sheet of fine emery polishing paper, the motion of the plate being maintained parallel to one edge of the plate. These surfaces were set parallel and close to each other, small pieces of plasticene being used to separate them. The scratches were arranged so that they were normal to the direction of the incident light. With the arrangement shown in fig 5(*a*) the angles of incidence and emergence are approximately 45 degrees. With the arrangement of fig. 5 (*b*) the angles of incidence and emergence are very small, the separation of the lines for the same distance between the surfaces of the glass plate being much greater. A photograph of the pattern was taken using the arrangement of fig. 5(*a*) and is shown in Plate III, fig 3 A mercury lamp and green filter had been substituted in place of the white light source, but it will be noticed that even using monochromatic light the lines are diffuse and in the form of broad bands.

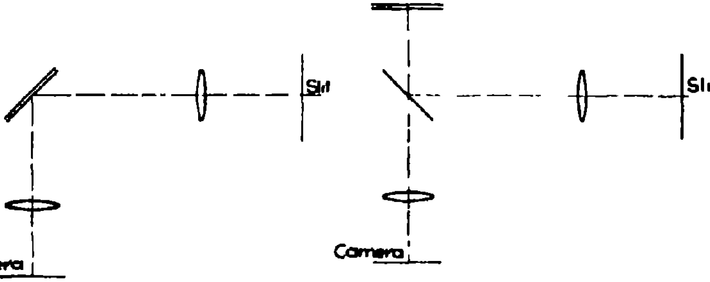

Fig 5.—(*a*) Experimental arrangement for observing diffraction pattern where separation of plates is small, θ and $\phi \approx \pi/4$.
(*b*) Experimental arrangement for larger separation of plates, θ and $\phi \approx 0°$.

When the lines were ruled at varying distances apart with a ruling engine, so as to maintain constant the depth of the scratched lines, the broad band effect was still evident A similar pattern was observed when parallel lines were scratched on one surface of a glass plate, the other surface of which was aluminized. These patterns correspond to those previously studied under the title of "The Colours of thick plates."

There are two ways in which we may interpret the production of these fringes. The first follows the lines suggested by the earlier workers.

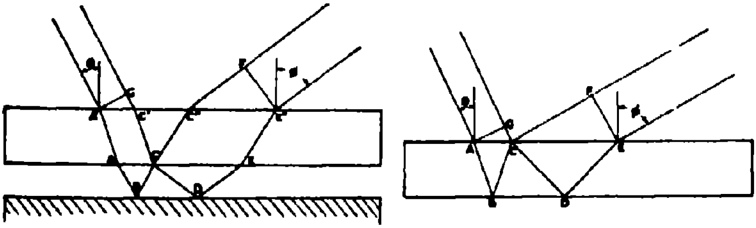

Fig. 6.—Explanation of colours of thick plates, using assumption of Stokes (*a*) air film.
(*b*) single plate

Let C (fig. 6(*a*)) be one of the lines of the lower surface of the top plate and d the distance between the plates. According to Young and Stokes it would be possible for ray A′ A B C C″ F to interfere with ray G C′ C D E E″. Both rays have been reflected from the bottom plate and scattered by the same scattering centre C. Provided we neglect the differential phase change for different angles of reflection, the optical path difference or retardation is

$$(AB + BC + C''F) - (GC' + CD + DE) = 2d\,(\cos\theta - \cos\phi).$$

Thus interference maxima will occur at angles corresponding to

$$n\lambda = 2d\,(\cos\theta - \cos\phi) \ldots\ldots\ldots\ldots 7.$$

where n is an integer.

It is interesting to compare equation (4) with that for the diffraction grating namely $n\lambda = d_1\,(\sin\theta - \sin\phi)$ where d_1 is the distance between the rulings. When $2d = d_1$ grazing incidence spectra for the grating corresponds to normal incidence spectra for the above.

The dispersive power of the system is represented by $d\phi / d\lambda = n/2d \sin\phi$. For small angles of ϕ, $d\phi / d\lambda$ becomes large, which accounts for the increased dispersion using the experimental arrangement shown in fig. 5(*b*) over that shown in fig 5(*a*).

When the parallel lines are scratched on one surface of a glass plate, the other surface of which is aluminized, the paths of the rays is given in fig. 6(*b*). Here

$$n\lambda' = 2d\,(\cos\theta' - \cos\phi') \ldots\ldots\ldots\ldots 8.$$

where λ' is the wave length of the light in glass, θ' and ϕ' the angles to the normal in glass. This would correspond to the arrangement studied by Whewell and Quetelet.

An alternative suggestion would be for two interference patterns to be produced separately as given earlier. Fig. 7 is drawn to illustrate this possibility, the full lines representing the production of one system (Set 1) and the broken lines the other system (Set 2).

For Set 1 system, i.e. light reflected between the plates and then scattered by C, we have, assuming glass surfaces

$$(n_1 + \tfrac{1}{2})\lambda = 2d\cos\theta \ldots\ldots\ldots\ldots 1$$

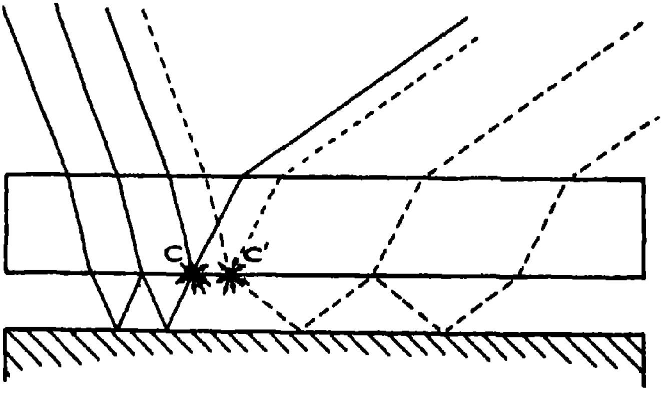

FIG. 7.—Alternative explanation of colours of thick plates.

and for Set 2 pattern, corresponding to light scattered by C′ and then reflected between the plates,

$$(n_2 + \tfrac{1}{2})\lambda = 2d \cos \phi \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.$$

The intersections of these two systems will be given by

$$(n_1 - n_2)\lambda = 2d\,(\cos \theta - \cos \phi) \text{ and}$$

when $n = n_1 - n_2$

$$n\lambda = 2d\,(\cos \theta - \cos \phi)$$

and this agrees with equation (7). It will be noticed that it is possible for the same scattering centre to produce both sets of patterns (Set 1 and Set 2), i e. for C and C′ (fig. 7) to coincide, and this will cover the original explanation of the production of the fringes if we neglect the possibility of several reflections before and after scattering We may therefore conclude that the second explanation is a more general one and accounts for the various types of interference patterns produced by scattering and reflection.

It was shown earlier that by comparing the pattern corresponding to Set 2 with a pattern observed when a frosted plate was placed at M_2 (fig 4), that a ray directly scattered from C′ was necessary to explain the Set 2 pattern. The equation for this pattern was shown to correspond to that of equation (2) above Since equation (7) for the colours of thick plates correspond to the intersection of the two patterns Set 1 and Set 2 we may, assuming equations (2) and (7), deduce the equation for Set 1 It is found that this corresponds to equation (1). To interpret this equation it is necessary to assume the interference of the rays given in fig. 1(*a*), one ray from the source reaches C without suffering reflections between the plates and is then scattered, whilst other rays are reflected between the plates before being scattered towards the observer.

Stokes affirmed that the pattern corresponding to the colours of thick plates could only be produced by light passing and repassing the same particle. He reached this conclusion as he was unable to observe the coloured pattern when he viewed a luminous point through a plate of glass both surfaces of which possessed scattering centres. An alternative explanation of his result would be that since neither surfaces contained a reflecting layer the intensity of the patterns produced would be low, and the resultant interference pattern difficult to see. The two patterns would also be produced similar to the manner of transmission Newton Ring patterns and for glass surfaces, that have not been made semi-reflecting, these have not the contrast of reflected interference patterns. The coloured pattern corresponding to the colours of thick plates for a white light source has nevertheless been observed by the author on viewing a distant lamp through a glass plate, one or both surfaces of which carries light scratches. A simple way of observing the pattern is to view at night time a distant lamp through a window of a railway carriage. These windows are usually scratched, particularly near the edges, the lines there being reasonably parallel. It is necessary for one surface only to possess the scattering centres, and the interpretation of multiple reflections given above can be simply modified to apply to this case. The pattern can be more clearly seen when the surface of the glass plate is at an angle to the direction of the light, the intensity of the reflected light being then greater than for reflections of normal incident light. The pattern is even more easily observed when a source is viewed through two nearly parallel surfaces that have deposited on them a light semi-reflecting layer, one of which has also been made capable of scattering light.

Conclusion

In concluding it may be stated that by using a source that provides line spectra in place of continuous spectra for example a mercury lamp in place of sunlight, the study of the colours of thick plates has been made more complete Two additional sets of interference patterns have been observed and the interpretation of these has suggested a different interpretation from that given previously for the colours of thick plates To account for the additional sets of interference patterns observed it is necessary to assume several reflections between the two surfaces of glass and the experiments described in this paper have shown that by increasing the number of reflections the resolution of these patterns has been increased It was observed that the locus of the intersections of these two patterns gives the system previously described under the title of the colours of thick plates Stokes concluded that it was necessary for two rays to be scattered by the same scattering element in order to account for the pattern observed by Newton His reason for this conclusion has been discussed and it is shown that an alternative suggestion satisfactorily fits in with the experimental results It is proposed that the colours of thick plates can be explained as the summation of a pair of patterns of a simpler Newton ring type which are produced independently the assumption of Stokes given above being unnecessary

Explanation of Plate

Fig 1 Photograph showing the [illegible] of the [illegible] interference patterns [illegible] produce the [illegible]

Fig 2(a)—Photograph [illegible] M [illegible] Fig 4

Fig 2(b)—Photograph [illegible] M [illegible] Fig 4

Fig 3—Photograph of patterns obtained [illegible] Fig 5(a) Separation of plates [illegible] μ

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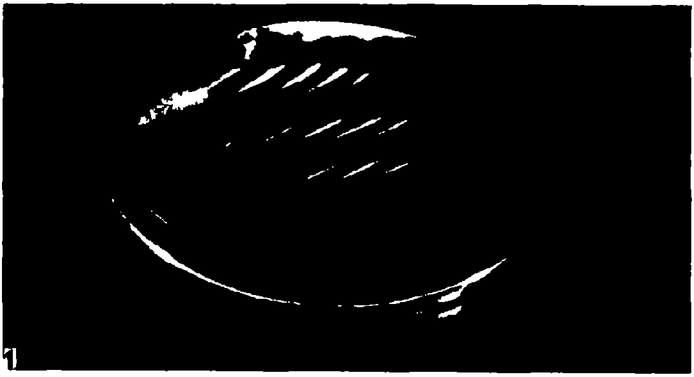

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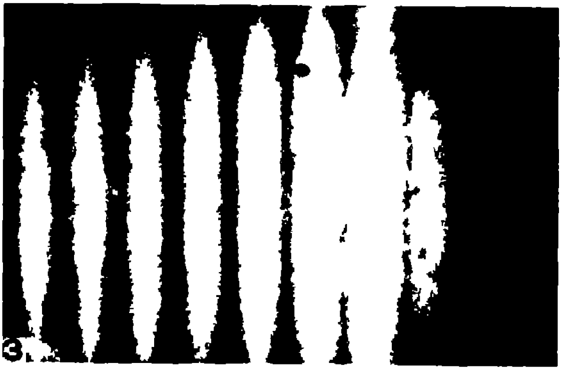

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[Proc. Roy. Soc. Victoria, 58 (N.S.), Pts. I-II, 1947.]

Art. IX.—*Alkali Hybrid Rocks of Port Cygnet, Tasmania.*

By A. B. EDWARDS, D.Sc., Ph.D., D.I.C.

[Read 8th November, 1945.]

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Introduction

The alkali rocks of the Port Cygnet district were first described by Twelvetrees in a series of short papers published between 1898 and 1907, and later by Paul (1906). They were thought to be of Permian age until Skeats (1917) showed that the related porphyry dykes near Woodbridge are intrusive into the Mesozoic dolerites. Further instances of this relationship were discovered subsequently at Port Cygnet by Reid (1922).

The rocks were known simply as felspar porphyries on account of their strikingly porphyritic character until Twelvetrees and Petterd (1898) attempted the difficult task of classifying them—one of the earliest petrological studies made in Tasmania. For this purpose they examined a collection of specimens whose field relations were not always known, some of them being not in situ when collected. They divided their specimens into three groups:—

(1) Effusive rocks—comprising hauyne trachytes, aegirine trachytes, melanite trachytes, and augite trachytes.

(2) Intrusive rocks—comprising sanidine-augite-hauyne aplites, and malchites (diorites).

(3) Plutonic rocks—comprising augite syenites, both with and without elaeolite.

The so called effusive rocks interpreted as contemporaneous lava flows in the Permian sediments exposed in the workings of the Livingstone mine 2 miles north east of Cygnet (Lovett) township were discovered to be thin sills or bedded dykes and in a later classification (Twelvetrees, 1902) the effusive rocks were grouped with the intrusive rocks as dyke intrusions At this time also Twelvetrees (1902A) drew attention to the unusual rocks occurring at Regatta Point on the western shore of Port Cygnet These he interpreted as the products of the differentiation in situ of a small stock which showed outward gradation from a core of syenite through essexite to a margin of the rare rock type jacupirangite His identifications of these rock types were confirmed by Professor Rosenbusch of Heidelberg to whom he submitted specimens and later by Paul (1906) who described in detail the collection of Tasmanian igneous rocks sent to Rosenbusch by Twelvetrees and made several chemical analyses of them The first chemical analyses of any Port Cygnet rocks were made by McLeod and White (1899)

In 1907 Twelvetrees again reclassified the Port Cygnet rocks into two groups —

(1) Plutonic rocks—comprising quartz augite syenite (akerite) elæolite syenite essexite monchiquitic shonkinite (monchiquitic nephelinite of Paul) and jacupirangite all these types occurring chiefly at or near Regatta Point

(2) Dyke rocks—comprising nepheline syenite porphyry (sometimes bearing hauyne) solvsbergite porphyry mica solvsbergite, tinguaite and tinguaite porphyry

In 1917 Skeats describing various dykes from the Oyster Cove and Port Cygnet districts referred to them by the simpler description of alkali porphyry

PRESENT WORK

In 1937 the author visited Port Cygnet to study in detail the supposed differentiated stock at Regatta Point Examination of these rocks has shown that there is no differentiated stock and that most of the unusual rocks reported by Twelvetrees and Paul such as essexites monchiquitic shonkinites and jacupirangites are not differentiates of a syenitic magma but hybrid rocks of very local development formed by reaction of a potash rich magma with a body of Mesozoic dolerite Mapping also revealed that a single type of fine grained alkali porphyry predominates throughout the district and that the unusual rock types that figure so largely in previous descriptions constitute somewhat less than 1 per cent of the total volume of igneous rocks exposed

Twelvetrees collections of rocks and thin sections have been dispersed and the collection at Heidelberg described by Paul is not available This, combined with the absence of any previous geological map showing the distribution of their rocks types or even the location of the described specimens makes it difficult to correlate them always with the descriptions that follow The collections of the Geology Departments of the Melbourne and Sydney Universities include a number of specimens from this area which were put at the author's disposal These specimens were gathered in the company of Twelvetrees but their localities are not always described precisely They do not differ however, in any particular from the rocks collected during the present investigation

The first geological map of the district was made by Reid (1922) based on a reconnaissance of the area in connection with a study of the Sandfly coal measures This map outlines the general distribution of the Tertiary igneous rocks without differentiating the types The map accompanying this paper (fig 2) is based upon Reid's map the former with some modifications being taken from an unpublished map prepared by the late Dr A N Lewis of Hobart and generously placed at my disposal by him Reid's boundaries have been considerably altered but the geological boundaries as now drawn are still conjectural in a number of places marked by broken boundaries in fig 2 However the possibility of my returning to the area to complete the field work is so remote that it is thought best to place the work on record as it now stands The localities of analysed specimens and other specimens specifically referred to in the text are indicated by numbers thus (81) on figs 2 and 4

General Geology

The Port Cygnet district is about 30 miles south of Hobart between the D'Entrecasteaux Channel on the east and the Huon Estuary on the west and south It is divided centrally by the Port Cygnet a tributary of the drowned Huon River system The main township is Cygnet formerly called Lovett at the head of Port Cygnet The area consists essentially of a broad belt of flat lying and tilted mudstones and shales of Permian age intruded by more or less north south belts of Mesozoic dolerite the more easterly dolerite masses being the more extensive (fig 1) The alkali rocks extend from Sturges Bay and Brooks Bay on the southern shore of the

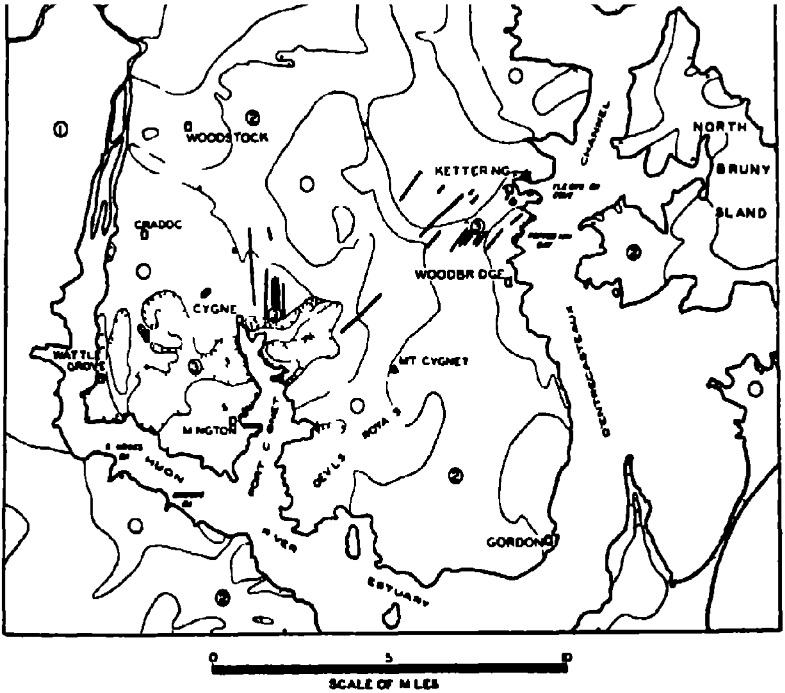

FIG 1 —Locality map showing the general geology of the Port Cygnet district
1 Permian sediments 2 Mesozoic dolerite 3 Alkali porphyry and dykes

Huon Estuary, north-eastwards to Oyster Cove on the shore of D'Entrecasteaux Channel their continuity being interrupted by the belts of dolerite that lie east of Mt Cygnet and the Devils Royals

The alkali rocks outcrop chiefly in the form of a partly unroofed stock of syenite porphyry, which is intrusive into both the Permian sediments and the Mesozoic dolerite As is shown in Fig 2, it occupies the greater part of the squarish peninsula to the south west of Cygnet township between the drowned valleys forming the Huon Estuary and the Port Cygnet Estuary and extends to Toby s Hill and Nicholl s Hill to the north east and east of the township respectively The irregular shapes of the outcrops and their discordant contacts suggest that the roof of the stock consists of a series of small steep sided cupolas

Associated with the stock are numerous dykes of syenite porphyry of varying composition These intrude both the stock the sedimentary rocks marginal to it and the dolerites Similar dykes outcrop on the southern shore of the Huon Estuary at Sturges Bay and Brooks Bay and to the north east of Cygnet on the eastern side of the belts of dolerite a number of identical syenite porphyry dykes and small sills occur in the vicinity of Woodbridge and Kettering and along the shore of D Entrecasteaux Channel from Little Oyster Cove to Peppermint Bay

The alkali rocks have induced only slight contact alteration of the Permian sediments and the dolerites The sediments are frequently silicified or indurated for a few feet from the margins of the larger intrusions and the dolerite shows slight uralitization Only at Regatta Point has dolerite been found which has been intensely altered by the porphyries At this locality a dyke like body of dolerite was invaded by a potash rich magma presumably a differentiate from the syenite porphyry stock and reaction between the potash rich magma and the dolerite has given rise to a variety of unusual hybrid rocks

The Alkali Rocks

THE SYENITE PORPHYRY (BANATITE) INTRUSION

The prevailing rock type in the Port Cygnet district is a relatively fine grained syenite porphyry When fresh it is light grey to buff coloured and consists of closely crowded squarish phenocrysts of plagioclase about 1 to 2 mm long with more sparsely distributed larger white to pinkish phenocrysts of orthoclase about 5 mm across and numerous phenocrysts of hornblende ranging from 0 5 to 3 0 mm in length and generally smaller than the felspars set in a felspathic ground mass

The plagioclase phenocrysts usually appear idiomorphic in thin section and are zoned Some crystals show oscillatory zoning The zoning is accompanied by both lamellar and Carlsbad twinning The plagioclase is optically positive and has a maximum extinction angle in the symmetrical zone at right angles to (010) of about 25° in the cores of the zoned crystals and about 20° in the marginal zones Cleavage flakes show a refractive index of 1 550 in one direction and a somewhat higher index in the direction at right angles These optical properties indicate that the plagioclase is andesine about Ab_{64} in the cores of the crystals and Ab_{68} at the margins

The orthoclase occurs as fewer but much larger idiomorphic crystals, which frequently include several small idiomorphic crystals of plagioclase together with small crystals of hornblende or pyroxene Only one or two such orthoclase crystals are present per square inch of thin sections The included plagioclase crystals are smaller than the plagioclase crystals occurring free in the ground mass suggesting that the orthoclase and plagioclase crystallized simultaneously Moreover there is an occasional parallel intergrowth of orthoclase and plagioclase Much of the orthoclase is untwinned but some crystals show simple twinning Some crystals are cloudy owing to slight kaolinization and there is a tendency for the kaolinization to develop zonally which suggests that the crystals show a zonal change in composition from core to margin like the plagioclase Cleavage fragments show refractive indices ranging from a little below to a little above 1 525 and the crystals are optically negative with 2V about 15° so that the felspar is perhaps best described as a variety of sanidine A partial analysis of a composite hand picked sample reveals that it has a composition approaching $Or_{43}Ab_{25}An_{32}$ (Table 3) The proportions of $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$ indicated are probably high owing to unavoidable contamination of the soda sanidine with small inclusions of plagioclase (andesine) Unusual though this composition is it appears from Alling's (1921 Fig 19) diagram to be a possible composition for a high temperature felspar Mackinen's diagrams as reproduced by Alling (1936 p 72) suggest that felspars of the sanidine barbierite series (delta anorthoclase series of Alling) can carry more $CaAl_2Si_2O_8$ in solid solution than other alkali felspars and that at temperatures of about 1000°C felspar of a composition $Or_{35}Ab_{45}An_{20}$ could crystallize simultaneously with a plagioclase of composition about $Or_{20}Ab_{40}An_{40}$ i e a potash rich andesine

Accompanying the felspars in each section there are a few rounded and embayed phenocrysts of quartz about 0 5 to 1 0 mm across

The proportion of ferromagnesian minerals varies from specimen to specimen They include both hornblende and pyroxene which occur as prismatic phenocrysts about 0 5 mm long with occasional prisms up to 3 0 mm long Hornblende is invariably present but pyroxene occurs only in occasional specimens The pyroxene was the earlier of the two to form since some phenocrysts consist of a core of pyroxene with a margin of hornblende The pyroxene is green to colourless and non pleochroic It has an extinction angle of about 45° on the prism face and has a 2V greater than 45° so that it is an augite It is probably similar in composition to the analysed pyroxene whose composition is given in Table 6 Analysis No 1 The analysed pyroxene was concentrated from a syenitic dyke (sanidine porphyry) at the mouth of Deep Bay on the eastern side of the Port Cygnet Estuary The hornblende is pleochroic from brown to yellow green and can be presumed to have a composition close to that of the hornblende analysis shown in Table 6 Analysis No 4 The analysed hornblende was taken from a dyke rock at Little Oyster Cove practically identical in appearance with the porphyries under discussion

Other minerals present in the porphyries are magnetite sphene and apatite which occur as crystals up to 0 3 mm long The ground mass consists essentially of orthoclase in small squarish crystals about 0 02 mm across so that it has an orthophyric texture At little interstitial quartz accompanies the orthoclase

In thin sections the porphyries closely resemble a dacite or toscanite Their syenitic affinities are more apparent from hand specimens and from their chemical composition Two chemical analyses were made one of a specimen from the saddle between Lymington and Wattle Grove near the centre of the Port Cygnet Peninsula (54), and ne from the cliff outcrop at Petchey s Bay, near the south west corner of the peninsula (72) The first specimen contains both pyroxene and hornblende the second contains only hornblende and the hornblende is partly replaced by jagged areas of calcite and a little epidote These analyses are set out in Table 1 Analyses Nos 1 and 2 together with analyses showing the average composition of akerite and quartz-monzonite, the two rock types that most closely resemble the syenite porphyries in chemical composition The resemblance is closer to the akerite than to the quartz monzonite but in addition to the textural difference the porphyries differ mineralogically from akerite in that hornblende rather than pyroxene is the dominant ferromagnesian mineral in them It is possible that the porphyry is chilled capping or border phase that passes into akerite in depth since akerite has been reported to occur near Lymington and at Regatta Point (Twelvetrees 1907 p 9) but too much significance should not be attached to these reports

The Lymington occurrence is described by Skeats (1917 p 157) as a dyke like body of akerite occurring at a point 1½ miles up the Forester Rivulet on the back road from Lymington to Mt Mary This area is now under cultivation and the akerite body was not located during the present investigation Two thin sections labelled as from this locality (Back Road) are included however among those loaned from the Geology Department University of Sydney One of these (S 10001) appears to be a true akerite It consists of large phenocrysts of sanidine up to 1 cm long in a coarse ground mass of clear plagioclase cloudy orthoclase greenish pyroxene and interstitial quartz Other minerals present are sphene apatite and magnetite The individual felspar crystals of the ground mass tend to be idiomorphic and are from 0 5 to 1 0 mm long The plagioclase which predominates is strongly zoned the cores consisting of basic andesine while the margins consist of oligoclase The orthoclase associated with it contains a little ex solution microperthite In the hand specimen this rock does not appear notably different from the typical syenite porphyry and in thin section it suggests a porphyry from which the fine ground mass has been excluded leaving only the phenocrysts crowded together It closely resembles some of the minor dyke rocks described below as syenite aplites at Regatta Point and elsewhere

The second section (S 10004) is a medium grained holo crystalline syenite, consisting essentially of orthoclase showing abundant ex solution microperthite and aegirine augite with a little interstitial quartz and some biotite apatite and sphene The orthoclase grains tend to be about 0 5 mm across but in patches are considerably smaller The aegirine augite crystals enclose cores of colourless augite and are generally prismatic in form This rock also has its counterparts among the syenite aplites of Regatta Point

Akerite is also recorded to occur at Regatta Point (Twelvetrees 1907) No such outcrop was observed during this investigation but two sections labelled akerite from this locality in the collection of the University of Sydney (S 10002 and 10003) closely resemble some of the syenite aplite dykes that occur in the zone of hybrid rocks at Regatta Point No 10002 consists essentially of squarish crystals of plagioclase from 1 0 to 2 0 mm across sometimes cloudy at the centre and orthoclase with lesser amounts of quartz augite hornblende magnetite and apatite The orthoclase is chiefly interstitial to the plagioclase or forms rims around the plagioclase crystals which are strongly zoned The central zones of the plagioclase crystals consist of basic andesine and the marginal zones are oligoclase Hornblende is much more abundant than the pyroxene which is colourless, and the magnetite crystals are rimmed with granules of sphene No 10003 is similar, but contains more orthoclase and quartz The orthoclase contains ex solution microperthite intergrowths and the plagioclase is restricted to inclusions in large orthoclase crystals It is commonly altered to sericitic or to zeolitic material

There is a close chemical resemblance between the syenite porphyry and the banatite that forms the uppermost zone of the differentiated laccolith of Mt Dromedary near Milton in New South Wales (I A Brown 1926) as can be seen from the analyses in Table 1 Holmes (1927) definition of a 'banatite as an orthoclase bearing quartz diorite fits well with the general mineralogical character of the Cygnet porphyry so that it seems better described as a form of banatite rather than of akerite Unfortunately Johannsen (1938 p 384) recommends that the term 'banatite' be disused on the grounds that it is vaguely defined and obsolescent

If the resemblance to the Mt Dromedary rock is more than superficial then it is possible that the deeper lying rocks in the Cygnet stock may be of monzonitic or even shonkinitic character

DYKE ROCKS

Numerous dykes are exposed in the cliff sections of the Cygnet Peninsula and in particular along both shores of the Port Cygnet Estuary Dykes are also exposed in various road cuttings and to a lesser extent elsewhere and in view of the thick soil cover that prevails over much of the area it may be assumed that many more dykes occur than are visible The dykes intrude the syenite porphyry stock the Permian sediments and the Mesozoic dolerites and include a variety of rock types The sequence of intrusion of the different types of dyke is not altogether clear

SYENITE PORPHYRY DYKES

Dykes of syenite porphyry that are practically identical in composition with the syenite porphyry of the main intrusion are found at intervals around its margin At Shag Point and Copper Alley (fig 2) and along the inland roads leading from Lymington to Wattle Grove and Petchey's Bay they can be seen intruded into Permian sediments Close to Cygnet jetty one such dyke can be seen invading the dolerite exposed in the low cliffs (38)

Along the eastern shore of the Port Cygnet Estuary syenite porphyry dykes from 2 to 40 feet wide occur in profusion in the cliffs from north of Crooked Tree Point as far as the Green Point jetty intruding Permian sediments

Occasional dykes of this type intruded into Mesozoic dolerite are exposed along the coast between Wattle Grove and the south western corner of the Peninsula along the Huon Estuary

A number of dykes and occasional small sills of similar syenite porphyry occur in the vicinity of Woodbridge and Kettering They are exposed along the shore of the D Entrecasteaux Channel at Little Oyster Cove Perch Bay and Peppermint Bay and in road cuttings They have been described by Skeats (1917) who showed that they intrude both the Permian sediments and the Mesozoic dolerite Hornblende is the only ferromagnesian mineral present in these rocks and it occasionally occurs as clots several centimetres across An analysis of the hornblende in one of the dykes in Little Oyster Cove is shown in Table 6, Analysis No 4

HAUYNE-SANIDINE-GARNET-PORPHYRY DYKES

This striking rock, known locally as 'magpie rock," occurs in a series of dykes and plugs extending northwards from Toby's Hill north and north-east of Cygnet township (fig 2) The Livingstone gold mine was situated on the contact of one such dyke on the north west flank of Livingstone Hill which is a spur of Toby's Hill The rock consists of numerous white to glassy tablets of sanidine up to 20 0 mm long by 3 0 mm thick together with crystals of black garnet 1 to 2 0 mm across, and less numerous black prisms of hornblende or pyroxene, up to 3 mm by 1 mm set in a grey felspathic ground mass The sanidine phenocrysts generally show parallel alignment with the strike of the dyke

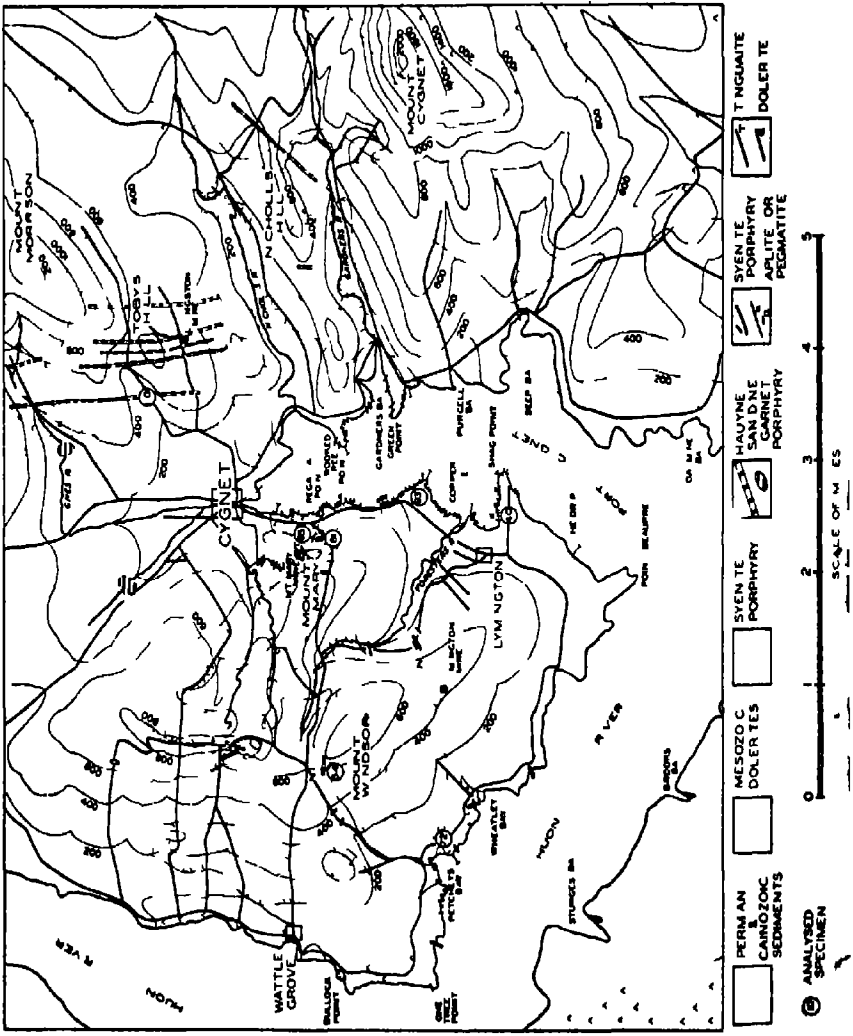

FIG 2—Geological sketch map of Port Cygnet [Geological boundaries modified after A M Reid form lines modified after A N Lewis]

Thin sections show that in addition to the sanidine phenocrysts there are smaller phenocrysts of zoned plagioclase with almost straight extinction indicating that it is oligoclase about Ab_{80} and numerous microphenocrysts of more or less altered hauyne up to 0 3 in width but generally smaller The hauyne occurs as inclusions in the sanidine phenocrysts and free in the ground mass It is identified by its isotropic character its consistent hexagonal form and its refractive index which is below that of sanidine It is commonly altered completely to a fibrous zeolite substance presumably natrolite More rarely it has altered to analcite or has been preserved unaltered In some sections the hauyne crystals are flecked with specks of bluish black dust Some of the hauyne crystals are altered to a micaceous aggregate Rosenbusch suggested that these crystals represented altered nepheline but their invariable hexagonal outline favours hauyne rather than nepheline

The garnet is a brown melanite as is proved by a chemical analysis of a small sample extracted from one specimen (Table 6 Analysis No 6) It occurs as strongly zoned idiomorphic crystals about 0 5 mm across frequently forming clusters (Plate IV fig 1) and sometimes intergrown with hornblende or pyroxene

The hornblende occurs commonly in small prisms which are pleochroic from deep brown to deep green An analysis of a small purified sample indicates that it is an iron rich variety of hornblende with a low magnesia content (Table 6 Analysis No 5) and relatively rich in potash and soda In these respects it is comparable with the hornblendes found in alkali syenites and related rocks

The pyroxene in some sections is aegirine strongly pleochroic from green to yellow and with a small extinction angle In other specimens it is aegirine augite often with a core of colourless augite in every respect similar to the pyroxene found in the syenite porphyry

In addition there are occasional coarse crystals of sphene and apatite though these minerals are not as abundant as in other rocks of the district

The ground mass has a pilotaxitic to trachytic texture and consists essentially of orthoclase microlites with fine shreds of hornblende minute flakes of yellow brown biotite granules of brown garnet and granules of magnetite Some of the minute hornblende shreds show a blue pleochroism suggestive of riebeckite

A chemical analysis of a typical rock (110) is shown in Table 2 Analysis No 2 The analysis with its high contents of potash soda and lime and its under saturated character with respect to silica emphasizes the unusual character of the rock

On the western shore of the Port Cygnet Estuary immediately south of the jetty at the northern headland of Copper Alley (fig 2) there occur two dykes about 10 feet wide identical in appearance with this rock One or other of these dykes appears to be the source of the rock described by Rosenbusch as a fine grained elaeolite syenite (Twelvetrees 1901 p 2 1902 p 296) The dyke rock from south of the Regatta Ground described by Rosenbusch is a garnetiferous mica solvsbergite (Twelvetrees 1901 p 3) and analysed by Paul (1906) (Table 2 Analysis A) was probably from this locality It is also probable that one of these dykes is the garnet trachyte analysed by McLeod and White (1899) The analysis is quoted in Table 2 Analysis B

A closely similar rock is exposed in a quarry just north of the road leading off from Regatta Point across the peninsula to Wattle Grove (81) Exposures are poor but the rock is apparently a dyke intruding the syenite porphyry, or else it is a deeper lying portion of the main intrusion The sanidine phenocrysts are light-grey and approach more closely the colour of the ground mass than those of the dyke rocks just described They lack pronounced parallel alignment and the ground mass is somewhat coarser grained with an orthophyric texture In addition, the rock contains more hornblende and less garnet The hornblende frequently encloses remnants of pyroxene and occasional grains have a core of colourless augite The garnet is finer grained than in the Toby s Hill dykes and does now show such well developed zoning It is generally intergrown with the hornblende sometimes in glomeroporphyritic clots Magnetite and occasional crystals of sphene are generally associated with the garnet hornblende clots and the association of these minerals is such as to suggest that all four are products of the breakdown of augite Occasional coarse crystals of sphene and apatite are also distributed through the ground mass Some hornblende occurs in the ground mass where it is patchily distributed in small granules and prisms and granules of magnetite are uniformly distributed through the ground mass

Hauyne microphenocrysts are present more abundantly than in the Toby s Hill rocks The hauyne is generally altered to a zeolitic substance whether included in the sanidine phenocrysts or free in the ground mass (Plate IV fig 2) The small plagioclase phenocrysts are corroded and armoured with a rim of orthoclase

A chemical analysis of this rock Table 2 Analysis No 1 shows that it is a little more acid and contains rather less soda than the analysed rock from Toby s Hill but is otherwise similar

Dykes that closely resemble this rock except that they apparently contain no hauyne have been found at Petchey s Bay and at One Tree Point

Sanidine Garnet Porphyry Dykes

Closely related to the magpie rocks are dykes of a still coarser sanidine garnet porphyry known locally as biscuit rock in which the abundant sanidine phenocrysts commonly measure 3 0 cm x 2 0 cm x 0 5 cm These large phenocrysts which are white to buff coloured are set in a grey felspathic matrix that is spotted with black phenocrysts of garnet about 1 to 2 mm across Dykes of this rock have been found intruding the syenite porphyry stock near the centre of the Cygnet Peninsula (66) and at Toby s Hill and Nicholl s Hill Similar dykes are exposed in cuttings through Permian sediments along the Lymington to Wattle Grove road at points 1 mile and 2 miles from Lymington (fig 2)

The exposed rock at all these localities is somewhat weathered so that it is not possible to establish the presence of hauyne in the rock with certainty Thin sections show the presence of a number of more or less hexagonal areas now completely altered to micaceous substances These areas occur both in the trachytic ground mass and as inclusions in the sanidine phenocrysts and they closely resemble in form and disposition the hauyne crystals of the magpie rock Some of the micaceous patches in the ground mass may represent altered ferromagnesian minerals since ferromagnesian minerals other than the melanite garnet appear to be absent from the ' biscuit rock ' The chief point of difference from the magpie rock however is the smaller proportion of plagioclase present Moreover partial analyses of the coarse sanidine phenocrysts of the two rocks indicate that the sanidine in the 'biscuit rock is richer in potash than the sanidine in the ' magpie rock" (Table 3), and has a composition approximating to $Or_{76}Ab_{18}An_6$

SANIDINE BIOTITE PORPHYRY DYKE

Near the Mt Mary mine occurs a dyke rock which contains rather sparsely distributed megaphenocrysts of sanidine comparable in size and appearance with those of the biscuit rock They are somewhat sericitized and are set in a ground mass of plagioclase laths and interstitial orthoclase studded with ragged laths and patches of biotite up to 1 0 mm long and with idiomorphic crystals of magnetite of about the same dimensions Numerous small flakes of biotite and muscovite occur in the interstices of the orthoclase laths The larger flakes of biotite are often composite clusters of numerous minute flakes so arranged as to preserve the crystal outlines of a pre existing hornblende The biotite and magnetite appear to be derived from the reaction of the hornblende with the potash rich residue that formed the ground mass The plagioclase laths of the ground mass show straight extinction so that they are oligoclase about Ab_8 A little apatite and sphene are present as accessories but there is no garnet

SANIDINE-PORPHYRY DYKES (TRACHYTES)

Narrow dykes that closely resemble trachytes occur intruding the metamorphosed dolerite at Regatta Point (1 2) and at the mouth of Deep Bay The dykes at Regatta Point consist of a number of small simply-twinned crystals of soda sanidine up to 2 mm long with microphenocrysts of augite showing some alteration to hornblende and an occasional garnet, set in a trachytic ground mass of orthoclase laths and uniformly distributed minute crystals of garnet prisms of green hornblende, and granules of magnetite The sanidine crystals all contain abundant microperthite and it seems probable from their situation in the zone of thermal metamorphism, that the unmixing of the microperthite resulted from the reheating of the metastable soda sanidine solid solution A further indication that these dykes probably predate the metamorphism and hybridization of the dolerite is provided by a specimen (12) from the zone of hybridization whose outcrop was largely hidden by sand but which appears in thin section to be a somewhat altered and recrystallized trachytic dyke

SANIDINE TINGUAITE DYKES

Immediately north of the jetty at the northern headland of Copper Alley two coarsely porphyritic dykes outcrop on the beach They consist of large white to buff phenocrysts of sanidine set in a dense green ground mass The dykes are each about 3 feet wide and have narrow chilled margins against the Permian sediments which they intrude and which are indurated at the contacts The sanidine phenocrysts tend to be aligned parallel to the long axes of the dykes They measure about 2 0 cm x 1 0 cm x 0 1 cm and are somewhat clouded The cloudy areas are restricted to areas of exsolution microperthite that are commonly developed in the central parts of the crystals Such microperthite is absent from the marginal parts of the crystals which are clear and the perthitic core is often differentiated from the clear margin by a distinct zonal structure The microperthite shows lamellar twinning with a symmetrical extinction angle of about 5° and it has refractive indices which straddle that of the enclosing sanidine so that it consists of albite oligoclase about Ab_{88} It lies in the cleavage direction of the sanidine elongated parallel to the prism faces The sanidine crystals also contain small inclusions of apatite and needles of aegirine and occasionally microphenocrysts of aegirine and melanite garnet The aegirine crystals are generally zoned and some have a core of colourless augite Some contain small inclusions of garnet The extreme margins of the sanidine crystals are often impregnated to a depth of about 0.1 mm, with minute needles of aegirine all lying with their long axes more or less parallel to the crystal boundary. A partial analysis of the sanidine from the more southerly dyke (93) shows that like the coarse sanidine crystals in the other dyke rocks it has a considerable soda content (Table 3). The calculated composition of the sanidine is $Or_{47}Ab_{39}An_{14}$.

Accompanying the sanidine phenocrysts are much smaller microphenocrysts of orthoclase and aegirine. The aegirine which tends to occur in clots is often altered to a secondary white mica.

The ground mass has a tinguaitic texture. It consists of a felted mass of aegirine needles about 0.1 mm x 0.01 mm intergrown with microcrystalline orthoclase and a little oligoclase. The felspars tend to be lath shaped, and in places show flow structure. Some nepheline may occur in the ground mass but it has not been identified with certainty although Rosenbusch claims to have detected it (Twelvetrees 1901 p 3). Dispersed through the ground mass are occasional lens shaped areas which consist of relatively coarse laths of oligoclase intergrown with orthoclase, and equally large prisms of aegirine. In some of these areas there are grains of andalusite strongly pleochroic from rose pink to colourless. In addition, there are occasional crystals of apatite and sphene.

To the north of these two dykes is a third green dyke which lacks the coarse sanidine phenocrysts. A thin section reveals an occasional phenocryst of sanidine and of aegirine with a core of colourless augite, in a microcrystalline ground mass of aegirine needles and orthoclase laths showing pronounced parallel orientation. Distributed through the ground mass are numerous small areas of a colourless mineral with low birefringence which would appear to be nepheline except that it appears biaxial and optically positive.

A further tinguaite dyke (95) outcrops on the hillside above the Mt Mary mine. This rock is identical with those just described except that it contains fewer coarse phenocrysts of sanidine and that in the coarser patches of the ground mass the place of andalusite is taken by a colourless mineral that resembles scapolite. It has a higher refractive index than the plates of felspar with which it is intergrown is uniaxial and negative with straight extinction parallel to the prismatic cleavage and has a moderately high birefringence. Crystals showing an optical figure have low polarization colours and are commonly crowded with inclusions in their central parts. It may be noted that Daly (1933 p 527) records the occurrence of primary scapolite in nepheline syenite from the Hastings Haliburton district of Ontario and Knight (1906 p 286) has recorded it in the ground mass of a leucite bearing tinguaite from Spotted Fawn Creek in the Yukon.

Twelvetrees (1898) originally referred to these coarsely porphyritic rocks as aegirine trachytes. Rosenbusch suggested that this name should be amended to tinguaite porphyry or better solvsbergite porphyry (Twelvetrees 1901 p 3). They have also been called tinguaite solvsbergite porphyry (Skeats 1917). Chemical analyses were made of the more southerly porphyritic dyke (93) immediately north of Copper Alley jetty, and of the dyke (95) above the Mt Mary mine (Table 2 Analyses Nos 3 and 4). The analyses confirm the tinguaite like character of the rocks but reveal that they are unusually rich in potash and poor in soda for typical tinguaites (Table 2 Analysis C). They are too poor in silica and soda, and too rich in lime and potash to be regarded as solvsbergites or their equivalents (Table 3 Analysis E). An approximate match is provided by a tinguaite with sanidine phenocrysts from the Bearpaw Mountains of Montana (Weed and Pirsson 1896) (Table 3 Analysis D), but this rock contains definite nepheline and sodalite in the ground-mass, whereas the soda in the Port Cygnet rocks occurs chiefly as a constituent of the felspar and the aegirine. The term "sanidine-tinguaite" has been adopted here for the Cygnet rocks as more descriptive than tinguaite-porphyry.

SYENITE-APLITE AND SYENITE-PEGMATITE DYKES.

Buff-coloured dykes, veins, and schlieren of syenite-aplite and syenite-pegmatite occur at a number of points along the beach and cliff section in the vicinity of Regatta Point, and occasional dykes of this character outcrop in the cliffs near Petchey's Bay, and along the eastern shore of the Port Cygnet Estuary. The dykes are up to 3 feet wide, and in exceptional cases 10 feet wide, and can be divided into two groups, those with typical aplitic texture, and those consisting of coarse plates of sanidine, up to 3·0 cm. long, closely packed in a finer felspathic matrix. The former are referred to here as syenite-aplites, and the latter as syenite-pegmatites. Their late origin is proved by the fact that they intrude the whole group of hybrid rocks exposed at Regatta Point.

The aplites, though apparently uniform in the hand specimen, are somewhat variable in composition Some (6*a*) consist essentially of interlocking equigranular grains of cloudy orthoclase, from 0·5 to 1·0 mm. across. Associated with the orthoclase are occasional grains of oligoclase, and rather more numerous grains of quartz The orthoclase crystals frequently contain some microperthitic albite in their central parts, though not in their margins. The oligoclase crystals are generally smaller and more prismatic than the orthoclase crystals The quartz tends to be interstitial In addition, there is a little brown biotite, a grain or more of magnetite, or of an altered ferro-magnesian mineral, and an occasional grain of apatite and zircon. One specimen contained a number of small irregular-shaped grains of blue corundum, with which was associated a little muscovite.

In some of the aplites (17), the plagioclase occurs as rather larger zoned crystals, and about equals the orthoclase in amount. The cores of the zoned crystals are a basic andesine, while the margins consist of oligoclase. The marginal oligoclase is generally cloudy, but the cores of andesine are clear, or are stained yellow along fractures. The small amount of quartz in such rocks is interstitial. Coarse crystals of sphene, up to 0·3 mm. in length, are dispersed through these rocks, together with occasional prisms of aegirine-augite, or colourless augite, the latter generally included in crystals of plagioclase. Some of the aegirine-augite crystals have a core of colourless augite. The ferromagnesian minerals are in places altered to chloritic substances, or to limonite, and the coarser ferro-magnesian crystals are somewhat corroded Rocks of this type (17) are identical with the rocks labelled "akerite, from Regatta Point", in the collection of the Sydney University Geology Department (S.10002, S.10003); and they bear a general resemblance to the syenite-porphyry.

The syenite-pegmatites (25, 26, 31) consist of abundant coarse tablets of sanidine, set in a ground-mass of coarse orthoclase plates, numerous coarse grains of magnetite, and a little green pyroxene, together with a small amount of interstitial muscovite and occasional coarse crystals of sphene. Much of the felspar is cloudy, and shows slight alteration to sericite or muscovite The coarse phenocrysts of sanidine contain patches of ex-solution microperthite, consisting of albite showing lamellar twinning, but the ground-mass orthoclase is free of such perthite, and there is practically no plagioclase associated with it, and very little quartz in the interstices. Some of the coarse sanidine crystals show isolated broad twin lamellae, which is perhaps the result of parallel growth of crystals. One such dyke contained a proportion of ferromagnesian minerals, but they are so largely altered to indeterminate chloritic substances that the original minerals cannot be identified

A chemical analysis of a typical pegmatite (25) gave the composition shown in Table 2 Analysis No 5 The analysis emphasises the fact that the rock is essentially felspar and indicates that the sanidine in this rock, as in the others contains a relatively high proportion of soda

GARNET ORTHOCLASITE DYKES

Occasional dykes of garnet orthoclase rock, about 1 ft wide are exposed in the beach section at Regatta Point These rocks closely resemble the syenite aplite dykes especially when weathered but differ from them in that they contain a notable amount of brown melanite garnet They are slightly younger than the aplites because instances were noted where a garnet orthoclase dyke (28) cut and displaced a syenite aplite dyke

In the hand specimen they are fine grained buff to pink rocks consisting of an occasional phenocryst of sanidine in an equigranular ground mass of felspar and dark ferromagnesian minerals Thin sections (19) show that the rock consists of occasional phenocrysts of sanidine microperthite, up to 1 0 cm x 0 5 cm in a groundmass of orthoclase microperthite melanite garnet and aegirine augite, in which the individual grains are about 0 5 mm across The pyroxene is generally prismatic and commonly consists of a core of colourless augite surrounded by a rim of deep green aegirine augite The garnet and the pyroxene tend to occur in clots together, in association with coarse crystals of sphene The garnet and the aegirine augite are in places intimately intergrown and it seems possible that they are products of the reaction of the magma prior to complete crystallization with some pre existing mineral, either augite or hornblende Other minerals present, in small amounts are brown biotite and apatite

Some of the garnet orthoclasite dykes (28) carry green hornblende as well as aegirine augite, and numerous small grains of magnetite In places biotite and garnet intimately associated, form fringes about remnants of the hornblende being clearly derived from its reaction with the potash-rich residual magma that formed the ground mass

A chemical analysis of a garnet orthoclasite (19) that carried only pyroxene with the garnet, is shown in Table 2 Analysis 6 The rock is distinctly richer in lime than the syenite pegmatite, with a little more soda, and proportionately less potash It is also distinctly richer in phosphorus When allowance is made for the greater content of ferromagnesians in this rock it is seen that the felspar is generally similar to that of the aplites and pegmatites

COMPOSITION OF THE FELSPAR PHENOCRYSTS

In all these alkali rocks, with the exception of the tinguaites, phenocrysts of plagioclase and sanidine are found side by side and from their association appear to have crystallized simultaneously Partial analyses were made of hand picked samples of the sanidine phenocrysts in several of the rock types, and these together with the calculated compositions of the phenocrysts are set out in Table 3 The sanidines in the tinguaites and in the hauyne-sanidine-garnet porphyry dykes are closely similar in composition, and are distinctly richer in potash than the sanidine phenocrysts in the syenite-poryhyry intrusion and presumably in the corresponding syenite-porphyry dykes The felspars in the syenite-pegmatite appear to be still more potassic assuming that the potash and soda in the rock analysis (Table 2 Analysis No 5) reflects the composition of the felspar while the sanidine phenocrysts in the biscuit rocks (sanidine garnet porphyries) are still more potassic The age relationships of the dyke rocks to one another is not clear but the general impression is gained that there has been a more or less progressive increase in the $KAlSi_3O_8$ content of the sanidine as differentiation has progressed This impression is strengthened by the common development of microperthite in the core of the sanidine crystals and its absence from the marginal zones of such crystals Alling's (1936 p 72) diagrams indicate that with slow cooling unmixing of solid solutions of albite and orthoclase (barbierite and sanidine) takes place to an increasing degree It may be assumed therefore that the cores of the sanidine crystals containing microperthite crystallized at higher temperatures and were more soda rich than the marginal zones of the crystals and that on cooling to the temperature at which the marginal zones crystallized the soda rich cores unmixed The marginal zones though solid solutions were poorer in soda and so more stable There is therefore good evidence of pronounced fractional crystallization in the development of the felspars

Parallel with the enrichment of the sanidine in $KAlSi_3O_8$ there was a progressive enrichment of the associated plagioclase phenocrysts in $NaAlSi_3O_8$ which is revealed by the changing extinction angles of these crystals both within individual zoned crystals and from rock to rock The simultaneous changes in composition of the two series of felspars is indicated diagrammatically in fig 3 in which the $KAlSi_3O_8$ content of the plagioclase is assumed from Alling's data The limits of the immiscibility gap between Or and An and between Or and Ab are taken from his three dimensional diagram for the system Or Ab An (Alling 1936)

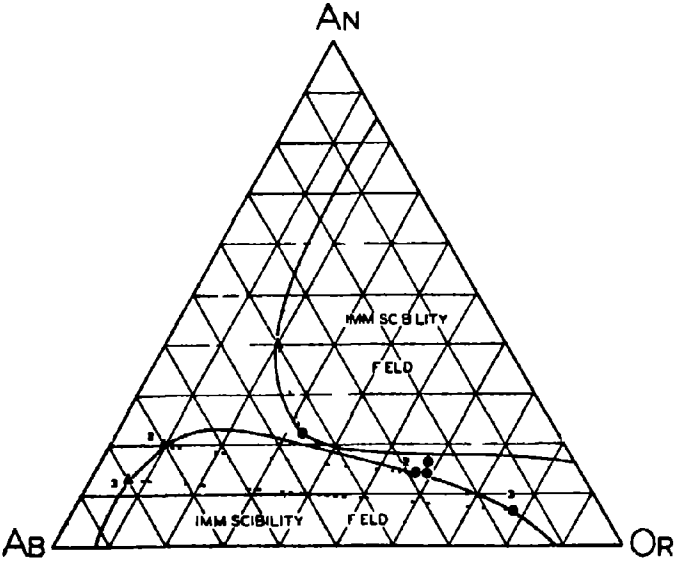

Fig 3—Diagram to show progressive changes in composition of the porphyritic felspars during differentiation 1 Syenite porphyry 2 Hauyne sanidine garnet porphyry sanidine tinguaite 3 Sanidine garnet porphyry

ORIGIN OF THE GARNET.

The garnet in potash-rich dyke rocks is a typical melanite (Table 6, Analysis No. 8) such as characterises some varieties of highly alkalic rock. It is a primary reaction mineral, and appears to have originated from a reaction of earlier formed augite or hornblende with the residual potassic magma that forms the ground-mass of the rocks. The ferromagnesian minerals, whether augite or hornblende, appear to have persisted in existence until a relatively low temperature, so that when they became unstable and reacted with the potassic magma, the lime in them was unable to crystallize as plagioclase. Some proportion of it was accommodated in the sodic plagioclase crystallizing at the time the ferromagnesians became unstable, and some was accommodated in the sanidine, but the amount of lime that could be accommodated in these minerals was limited by the temperature of the magma, and was decreasing with further fall in temperature. The magma, however, was saturated with respect to alumina, so that the lime-garnet molecule became a substitute for the higher temperature lime-plagioclase molecule, and portion of the iron from the ferromagnesian minerals was also included in the garnet. The magnesia from the ferromagnesian mineral tended to combine with the potash of the magma to form biotite

This process, of the reaction of ferromagnesian minerals with potash-rich fluid, after becoming unstable at a relatively low temperature, with the subsequent formation of melanite garnet and biotite, can be followed in detail in the hybrid rocks next to be described. In these rocks the process is seen in exaggerated form, because the hybridization involves the incorporation of a considerable proportion of ferromagnesian minerals directly into a potash-rich rest-magma.

McLeod and White (1899) described the occurrence of a garnet of most unusual composition (Table 6, Analysis B) from a "garnet-trachyte" dyke south of Regatta Point, and proposed the name "johnstonotite" for it. The locality of this dyke was not given with exactitude, but it appears to have been one of the hauyne-sanidine-garnet-porphyry dykes immediately south of the jetty on the northern headland of Copper Alley The uniform appearance of the garnet in this rock and in all the rocks examined raises doubt as to whether the sample of garnet analysed by McLeod and White was pure Its high manganese content contrasts strongly with the low manganese content of all the analysed rocks other than this dyke (Table 2, Analysis B)

HORNBLENDE.

The analyses of the hornblende from the syenite-porphyry dyke at Little Oyster Cove, and from the presumably younger hauyne-sanidine-garnet-porphyry dyke on Toby's Hill, (Table 6. Analyses Nos. 4 and 5) suggests that there was a tendency for the iron and lime contents of the ferromagnesian minerals to increase relative to the magnesium content as differentiation progressed

The Hybrid Rocks of Regatta Point

A belt of hybrid rocks, formed from the reaction of a potash-rich syenitic magma with a body of earlier intruded dolerite, is exposed in the beach and cliff section, extending southwards from the Cygnet jetty for about 800 yd., past Regatta Point (fig. 4). The least altered dolerite is at the northern end of the section, close to the jetty. The shape of the dolerite body is not clear from the exposures, but it appears to have been a moderately large dyke, trending oblique to the cliff line.

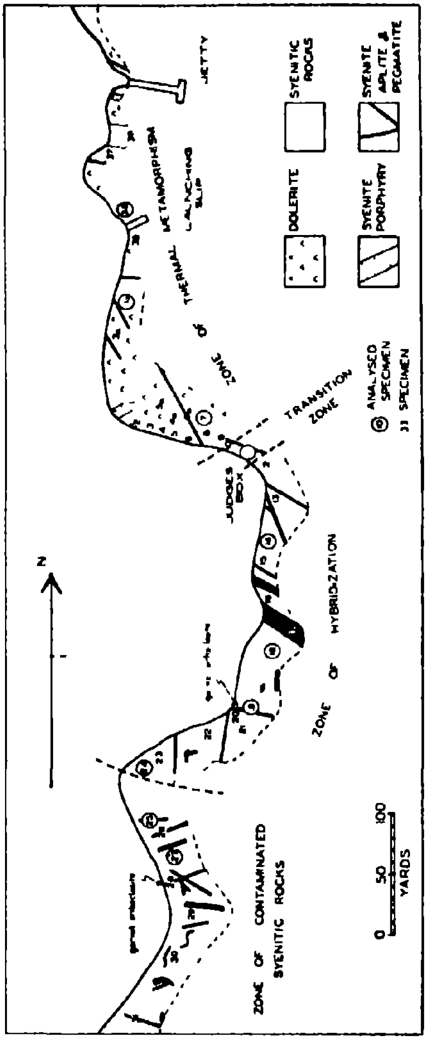

FIG. 4 — Map showing the distribution of hybridized rocks at Regatta Point

The rock exposures can be divided into four sections of unequal length, which can be distinguished in the field, and correspond to the appearance or disappearance of various minerals that mark stages in the process of hybridization. The first section, which extends for about 200 yards south from the jetty, nearly to Regatta Point, consists of dolerite that has been altered chiefly by contact metamorphism, with a more or less complete transformation of the pyroxene of the dolerite to hornblende and magnetite. A little potash and silica appear to have been introduced during the metamorphism, but the change in chemical composition of the rock as a whole throughout this section is slight, and the rock still preserves its doleritic texture, and its dark colour. At the northern end of the section, the dolerite is traversed by a dyke of syenite porphyry and two sanidine porphyry (trachyte) dykes These dykes were intruded before the hybridization because they appear to have suffered thermal metamorphism At the southern end of the section there are also several narrow dykes of syenite aplite and syenite pegmatite intruding the dolerite

The second section is only about 50 yards long and is marked by the breakdown of the plagioclase of the dolerite which results in the disappearance of the doleritic texture from the rock This was accompanied by a transformation of the secondary hornblende to colourless augite and by the introduction of potash and perhaps silica in increasing amounts The rock though dark has a granular speckled appearance in hand specimen

The third section which extends round from the face of Regatta Point to the head of the embayment on its southern side a distance of about 200 yards consists of true hybrid rocks rich in both lime and potash In these rocks the augite formed in the stage of reaction equivalent to that of the narrow transition zone has reacted more or less completely with the potash rich magma to form lime iron garnet (melanite) and biotite while any titania has been precipitated as coarse crystals of sphene The greatest variation in rock types is found in this section The rocks can be divided into three groups (1) those as rich or richer in lime than the dolerite (2) those poorer in lime than the dolerite and grading into syenite and (3) dyke rocks consisting of syenite aplite syenite pegmatite and occasionally garnet orthoclasite which are younger than the hybrid rocks The various types of hybrid rock show no regular distribution but occur in irregular patches and schlieren and show rapid transition from one to another

At the southern end of this section the hybrid rocks grade into a fourth section consisting of a contaminated syenitic rock which is cut by numerous narrow dykes of syenite aplite and syenite pegmatite with an occasional dyke of garnet orthoclasite This rock differs but little from the potash rich lime poor rocks of the hybrid zone and is not described separately

THE DOLERITE

Where least affected by the syenitic magma the dolerite (36) consists essentially of basic plagioclase (labradorite about Ab_{48}) and pyroxene with a small amount of granophyrically intergrown quartz and alkali felspar probably orthoclase in view of the relatively high potash content of the rock (Table 4 Analysis No 1) in the interstices of the plagioclase laths Two pyroxenes are present generally closely associated or intergrown and as is characteristic of the Mesozoic dolerites in Tasmania (Edwards 1942) one is an augite with 2V greater than 45 degrees while the other is a nearly uniaxial pigeonite Both occur as crystals up to 2 0 mm x 0 5 mm and show prominent sahlite striations in a direction making an angle of 10 degrees with the prismatic cleavage In some sections they tend to ophitic relationship with the plagioclase which occurs as stumpy unoriented laths generally about 0 25 mm x 0 05 mm with occasional coarser platy crystals

The margins of the pyroxene grains are frequently choked with magnetite dust and generally show some alteration to green hornblende In some specimens (36) this alteration is relatively slight (Plate IV fig 5) in others (1a) the zone of hornblende is as wide as the core of unaltered pyroxene but the chemical composition of the rocks shows little difference (Table 4 Analyses Nos 1 and 2) The hornblende in the rock is derived solely from the breakdown of the pyroxenes under the conditions of contact metamorphism It is pleochroic with X — pale yellow Y — yellowish green, Z — deep green

The original magnetite of the dolerite occurs as sparse grains up to 0 25 mm x 0 25 mm It is generally surrounded by a reaction rim of minute flakes of biotite which tend to grow columnar fashion normal to the surface of the magnetite grain The biotite is pleochroic from straw yellow to deep brown Such secondary biotite is developed only from the original coarse magnetite and does not occur with the magnetite dust in the margins of the pyroxene Such biotite fringes around magnetite grains are not normal to the dolerite and appear to be a product of reactions induced by the contact metamorphism

Quartz occurs in small amounts but even so is present in unusual amounts for typical dolerite and it seems possible that some of it has been introduced from the syenitic magma together with the orthoclase that forms micrographic intergrowths with it

Chemical analyses of the little altered dolerite (36) (Table 4 Analysis No 1) and of its composite pyroxene (Table 6 Analysis No 3) show that the rock is a considerably differentiated phase of the Mesozoic dolerites that are so widespread in this and other parts of Tasmania The analyses show that it differs from described variations of the dolerites in that it contains almost twice as much MgO and several per cent less Al_2O_3 than any previously analysed Tasmanian dolerite containing only 9 5 % CaO This indicates that it has an unusually high content of pyroxene for the stage of differentiation corresponding to its CaO content and to the relatively iron rich character of its pyroxene It has been postulated from a study of the large dyke like mass of dolerite of Gunning s Sugarloaf in the Midlands district of Tasmania (Edwards 1942 pp 474 604) that such rocks are to be expected at depths unspecified in dyke masses that have undergone differentiation after emplacement but the Regatta Point dolerite may not have originated in this way

A narrow dyke of unaltered dolerite (40) intruded into the Permian sediments on the south side of Copper Alley about a mile south of Regatta Point (fig 2) shows a comparable richness in MgO relative to CaO (Table 4 Analysis No 5) This dyke is only 2 feet wide so that it could not have undergone differentiation to such a degree after its emplacement It provides therefore the first recognized instance in Tasmania of intrusion of dolerite magma either after it had undergone differentiation or else when it was in process of differentiating The dolerite at Regatta Point which appears to be a somewhat larger dyke though not remotely comparable in size with the dyke like mass forming Gunning s Sugarloaf, also probably underwent differentiation prior to its emplacement Under such conditions it is possible that differential movement of the already formed crystals and of the still fluid portion of the magma (filter press action) may have contributed to its unusual composition, and to that of the Copper Alley dyke

From Twelvetrees (1902A) description of the distribution of the various rock types at Regatta Point one would conclude that the metamorphosed dolerite corresponded to his so called jacupirangite Comparison of the analyses of the dolerite with those of jacupirangite (Table 4, Analyses A B) show how unlike the two rock types are It is apparent however from the descriptions of the rock given by Rosenbusch (Twelvetrees 1902A) and by Paul (1906) that the so called ' jacupirangite ' consisted chiefly of augite nepheline and orthoclase, and as indicated later, was a variety of hybrid The volume of such basic hybrid rocks must have been very small—limited in fact to a few hand specimens—for careful search failed to reveal any mass of comparable rock. It seems possible that Twelvetrees confused the two rocks, and regarded the specimen described by Rosenbusch as representative of the dolerite, because he clearly regarded the thermally metamorphosed dolerite as "essexite" and as an intermediate stage of the differentiation of the syenite into jacupirangite. Otherwise, it is remarkable that he made no reference to the dolerite as such.

THE ZONE OF THERMAL METAMORPHISM.

This zone extends from the Cygnet jetty to about half-way along the northern side of Regatta Point (fig 4). Throughout it the plagioclase of the dolerite remains practically unaltered, and preserves the doleritic texture of the rock The pyroxene and magnetite, however, are more or less completely altered to hornblende and biotite, respectively.

The alteration of the pyroxene crystals begins with the precipitation of minute granules of magnetite "dust" in the margins of the crystals, and the development there of minute prisms and granules of green hornblende. As the change progresses, the hornblende spreads to the cores of the pyroxene crystals, along cleavages, and along the sahlite striations. Simultaneously, the individual hornblende granules grow together to form coarser crystals, so that in the intermediate stage of the change, a pyroxene crystal has been converted more or less completely to a group of four or five small crystals of hornblende, generally containing numerous inclusions of magnetite. The magnetite granules show a similar tendency to grow together into larger grains, but in some crystals they begin to alter to minute flakes of biotite In the final stage of the alteration (7A), an original pyroxene crystal is replaced by a single large crystal of hornblende, somewhat ragged at the margin, and often with a narrow fringe of minute hornblende prisms that have not been absorbed into the main crystal (Plate IV, fig. 6). Such coarse crystals of hornblende usually include scattered grains of magnetite, but ultimately they clear themselves of such inclusions In some hornblende crystals, the original cloud of magnetite "dust" is converted into a cloud of minute flakes of biotite. These subsequently grow together to form rather coarser crystals of biotite that remain intergrown with the hornblende, or migrate to its margin.

The biotite flakes rimming the original coarse magnetic crystals undergo a similar process of growth into a few large flakes, though these rarely attain the size of the hornblende crystals Where the original magnetite contained titania, presumably as intergrown ilmenite, the titania is precipitated as crystals of sphene, some of which are crowded with minute flakes of biotite. One instance was observed of a rim of sphene enclosing a grain of magnetite.

In a number of places the coalescence of the early-formed minute prisms of hornblende and flakes of biotite to form coarse crystals has been prevented by the introduction into the rock of alkali felspar, apparently orthoclase. The orthoclase crystallized in the areas of altering pyroxene, as a mosaic of small allotrioblastic grains with highly crenulate margins, and as they grew, these grains caught up the small grains of hornblende and biotite as inclusions, or else pushed them into the grain boundaries of the orthoclase mosaic, so that a cloud of ferromagnesian granules dispersed through a mosaic of alkali felspar crystals marks the former presence of a large crystal of pyroxene. Such areas of alkali felspar and clouds of dispersed granules of hornblende and biotite are generally associated with patches of microgranophyre, which represent either original interstitial orthoclase recrystallized with silica set free by the alteration of pyroxene to hornblende or else introduced quartz and orthoclase derived from the syenitic magma An analysis of the hornblende (Table 6, Analysis No 6) shows that it has much the same silica content as the original pyroxene (Table 6 Analysis No 3) so that it seems unlikely that the silica was derived from the change of pyroxene to hornblende However, if the quartz and orthoclase were introduced, the amount introduced must have been small because an analysis of altered dolerite (7A) in which the pyroxene is completely altered to coarse hornblende (Table 4 Analysis No 43) shows very little difference in these respects from the analyses of the least altered rock (Table 4 Analyses Nos 1 2) It is to be noted however that these analyses contain slightly more potash than is normally found in the Tasmanian dolerites and are relatively rich in SiO_2 All of these rocks may therefore contain a small amount of introduced potash, and probably quartz and it is noticeable throughout this zone that the alteration of the pyroxene is always more advanced in sections that contain an abundance of microgranophyre than in sections in which it is more or less absent Moreover in some sections the plagioclase crystals have been somewhat invaded by patches of microgranophyre or fractures in the plagioclase crystals are filled with orthoclase veinlets that connect patches of granophyre with one another or with areas of orthoclase crystals Some such veinlets cross several adjacent plagioclase crystals

The ferromagnesians in these altered dolerites also show some evidence of mobility In one section the rock is traversed by a veinlet 0 1 0 2 mm wide of small colourless pyroxene crystals with some associated sphene and pyrite The pyroxene gives place along the length of the veinlet to fine grained orthoclase and quartz In other sections veinlets of hornblende fill fractures and cleavages in plagioclase crystals the veinlets in some instances being connected with large crystals of hornblende

These rocks in which the pyroxene is more or less completely altered to hornblende correspond to the essexite of Twelvetrees (1907) and Paul (1906 pp 280 283)—' a dark dioritic looking rock below the Regatta Box (containing labradorite and andesine felspar augite hornblende and quartz Paul s detailed description leaves no doubt as to the correctness of this correlation Comparison of their composition with that of essexite (Table 4 Analysis E) reveals their essential difference from this rock despite a resemblance in some respects

THE TRANSITION ZONE

The relatively narrow transition zone that separates the zone of thermal alteration from the hybrid rocks proper is characterized by the breakdown of the original plagioclase with the consequent destruction of the doleritic texture of the rocks Thin sections (11) show that the plagioclase crystals become dissected by a network of narrow veins of alkali felspar which slowly widen leaving isolated remnants of the plagioclase enclosed in the alkali felspar until in the final stage no plagioclase remains at all The alkali felspar in these veins appears to be albite because in one instance it showed a refractive index lower than that of the disintegrating plagioclase, but higher than that of the cloudy crystals of orthoclase surrounding the plagioclase The albite is clear and untwinned

This breakdown of the plagioclase is accompanied by a transformation of the hornblende to granular aggregates of colourless augite (Plate V, figs 7 and 8) Assuming that the composition of the augite is similar to that of augite of similar appearance in the hybrid rocks proper, it contains much more lime (Table 6 Analysis No 2) than the hornblende it replaces

(Table 6, Analysis No. 6). This lime is derived, presumably, from the breakdown of the plagioclase Some evidence that this is so is provided by the occurrence of granules of augite in the albite veinlets between residual areas of plagioclase. The iron ore granules in the hornblende are unaffected by the change, so that much of the augite is at first filled with inclusions of iron ore (Plate V., fig. 8) As the augite grains coalesce, however, they clear themselves of such inclusions. Traces of primary pyroxene still remain in some sections, and grains of coarse magnetite, with rims of coarse biotite flakes, are still present.

Pyrite, apatite, orthoclase, and perhaps quartz, have been introduced into the rock, and occur in small veins. One such vein was observed cutting through a clot of small equi-granular crystals of hornblende, preserved from alteration by a fringe of granophyre

Despite the reconstitution that the rock has undergone in this narrow transition zone, its bulk composition has changed very little. An analysis of a representative specimen (11) (Table 4, Analysis No. 4) shows a slight increase in soda and potash over the less altered dolerites, and some reduction in magnesia content, but is otherwise similar.

THE ZONE OF HYBRIDIZATION.

The hybrid rocks proper can be divided into two groups (excluding the dyke rocks that intersect them). (1) leucocratic rocks, poorer in CaO than the dolerite, but much richer in K_2O, and (2) melanocratic rocks, as rich or richer in CaO than the dolerite, and moderately rich in K_2O This division is artificial, because there is a frequent gradation between the two types, which are irregularly distributed throughout the outcrops on the beach and in the cliff face. The grain size of the hybrid rocks is similar to that of the dolerites, but the texture is more granular, and the higher proportion of felspathic constituents makes even the most basic of the hybrid rocks appear greyer than the metamorphosed dolerite In a number of specimens, particularly the more basic rocks, the felspars (and felspathoids) tend to occur as large poecilitic crystals (1–2 mm.) with numerous inclusions of the several ferromagnesian minerals In some, the orthoclase tends to be porphyritic. The "phenocrysts" may enclose plagioclase residuals, but do not enclose ferromagnesian minerals.

The hybrid rocks all consist essentially of orthoclase and a lime-rich pyroxene, which is generally more or less altered to biotite and brown melanite garnet, together with areas of a lime zeolite, probably scolescite, notable amounts of magnetite, and coarse idiomorphic crystals of sphene and apatite. Some specimens, particularly the lime-rich ones, contain residual plagioclase, generally armoured about by broad zones of orthoclase, and some contain nepheline. The differences in chemical composition shown by these rocks (Table 5) arise largely from differences in the relative proportions of ferromagnesian minerals and orthoclase. The analyses show that K_2O is present in all these rocks in considerably greater amounts than in the dolerite, and there can be little doubt that most of this potash is introduced from the magma represented by the veins and schlieren of syenite-aplite and syenite-pegmatite that traverse the rocks, and in places appear to grade into them The introduction of the potash appears to have rendered the rocks more or less fluid, and has led to local concentrations of the ferromagnesian minerals, which locally dominate the felspathic constituents Occasionally the pyroxene crystals have segregated into clots 2 to 3 cm. in diameter. It is to be noted that the leucocratic rocks (Table 5, Analyses 1, 2) bear a close chemical resemblance to the hauyne-sanidine-garnet porphyries (Table 2) and related dyke rocks.

The pyroxene is a lime rich variety (Table 6 Analysis 2) closely resembling the pyroxenes in the alkali porphyries (Table 6 Analysis 1) Presumably, addition of lime from the dolerite to the syenitic magma has led simply to an increased crystallization of augite This pyroxene consists generally of a colourless core with a green marginal zone In basal sections the green zone is strongly pleochroic from green to yellow and has a small extinction angle so that presumably it consists of aegirine Such green rims appear to be lacking in the rocks of the transition zone described above, and appear only in the hybrid rocks proper in which the plagioclase has largely or completely disappeared As indicated the disappearance of the plagioclase is a process of solution in which the lime soda and alumina of the plagioclase become separated The lime reappears in the hybrid rocks partly as diopsidic pyroxene (the colourless cores of the pyroxene crystals) and partly as lime zeolite In some specimens the soda reappears as albite and in others as nepheline but much of it presumably enters into the later forming pyroxene to form rims of aegirine augite round the cores of diopsidic pyroxene The common presence of albitic perthite in the sanidine crystals of the syenite pegmatite veins suggests that some of the soda in the hybrid rocks was introduced along with the potash and there is little to indicate what proportions of the soda were derived from these two possible sources The alumina appears to have entered the magma intensifying its tendency to become saturated in this respect

In all but a few sections the pyroxene has reacted to some degree with the syenitic magma The magnesia and some of the iron in the pyroxene have combined with the introduced potash to form a magnesia rich biotite (Table 6 Analysis 7) while the lime and the remainder of the iron have combined to form a brown garnet whose composition is probably similar to that shown in Table 6 Analysis 8 This reaction has the effect of returning to the magma about 25% of the SiO_2 originally incorporated in the augite The biotite is pleochroic from a brownish or a greenish yellow to almost black Some crystals enclose irregular lighter coloured patches which suggest ghosts of pyroxene grains others contain inclusions of apatite and rarely of pyroxene In some rocks in which the alteration of the pyroxene is advanced the biotite occurs as scattered plates 2 to 3 mm across The analysed biotite was a hand picked sample of these coarse crystals

The appearance of the garnets varies somewhat In many sections they appear first as small blebs or granules These tend to grow together into larger grains that show rudimentary crystal outlines The larger grains contain inclusions of sphene pyroxene biotite and occasionally orthoclase With increasing size the crystals develop zoning a lighter brown core passing into a darker or clove brown margin

The progress of this reaction of the pyroxene with the potassic magma to form garnet and biotite varies even within a single thin section In some sections almost every grain of pyroxene is rimmed with a fine grained intergrowth of garnet and biotite (Plate V fig 9) in others the pyroxene crystals are more or less completely altered to an intergrown garnet and biotite (Plate V figs 10 11) In others some grains of pyroxene have reacted while adjacent crystals appear unaffected In a number of sections the reaction is much more pronounced where the pyroxene crystals are in contact with orthoclase grains than where they are embedded in patches of zeolite but this is not invariably so In the coarser grained rocks the biotite and garnet tend to separate and form relatively large individual crystals (Plate V fig 12) but in the finer grained rocks they are often intimately intergrown In some sections the amount of garnet and biotite exceeds that of pyroxene but generally the relative proportions of the three minerals vary greatly from place to place in a single section Only occasionally has the pyroxene been completely replaced or nearly so but this is the case in some of the more potash rich rocks

The pyroxene is characteristically associated with a zeolitic mineral that occurs as irregular areas and narrow veins up to 1 0 mm wide The zeolite consists of fibrous rosettes which when they are well grown and are not weathered are anisotropic with low polarization colours (Plate IV fig 3) Frequently however they show only vague anisotropism and many patches which are cloudy in ordinary light appear isotropic so that there may be more than one variety of zeolite present The anisotropic mineral scraped from a veinlet has a refractive index between 1 515 and 1 520 and gives a strong positive microchemical test for calcium The zeolites with a refractive index of this order are the lime soda zeolite thompsonite and the lime zeolites scolescite and laumontite The low birefringence best fits scolescite Previous investigators have regarded this mineral as natrolite pseudomorphous after nepheline It is to be noted however that the zeolite is most abundantly developed in rocks which while they contain distinctly more potash than the dolerites contain if anything less soda The soda in the analyses can be accounted for largely by the aegirine rims of the pyroxene crystals which would leave altogether too little soda for the zeolite to be natrolite The zeolite occurs in greatest abundance in the lime rich rocks and is present only in small amounts or is absent in rocks rich in potash and relatively poor in lime Moreover in the lime rich rocks the lime content equals or exceeds that of the dolerite and it seems unlikely that there is sufficient pyroxene present in them to account for the whole of the lime It is concluded therefore that the zeolite is a lime rich variety the lime being derived from the breakdown of plagioclase from the original dolerite As confirmation of this one section contains residual plagioclase more or less protected by rims of orthoclase in which the plagioclase appears to show all stages of gradation into the zeolitic substance

The veinlets of zeolite are of late formation since in some sections they cut across large orthoclase crystals displacing the two halves (Plate IV fig 3) In other sections the zeolite veinlets cut through garnet biotite clots while frequently the zeolite fills the interstices between orthoclase crystals The more basic specimens (18) (Table 5 Analysis 4) contain a proportion of coarse grains of fresh nepheline up to 0 3 mm across The nepheline like the orthoclase encloses numerous smaller crystals of pyroxene garnet and biotite It can be distinguished from the orthoclase only by its uniaxial figure and its negative character so that it is easily overlooked Paul (1906) analysed a still more basic rock (Table 5 Analysis A) in which nepheline was apparently more abundant and biotite was present as occasional large crystals This rock is reported to have occurred as scattered stones not in situ between the Regatta Box and the Point Rosenbusch referred to it as a mica nephelinite with the habit of a monchiquite (Twelvetrees 1902) and Paul (1906) called it a monchiquitic nephelenite with shonkinitic affinities Twelvetrees (1907) later classed it as a monchiquitic shonkinite Its general resemblance to shonkinite in chemical composition may be seen by comparing Analyses A B and C in Table 5 but it is more basic than typical shonkinite

The rock described as jacupirangite (Twelvetrees 1902A) appears to be an even more basic variety from which orthoclase was excluded It consisted essentially of nepheline augite sphene garnet apatite magnetite and biotite A careful search was made for this rock without success and it is certain that it must be of very restricted occurrence—no more than a localized segregation—though Twelvetrees' (1902A) description would lead one to think otherwise

The felspar in these rocks is chiefly orthoclase In some sections it tends to be porphyritic with lath or platy phenocrysts from 1 to 3 mm long in a finer grained groundmass of lath like orthoclase grains about 0 1 mm long In other sections the orthoclase forms equigranular plates 1 to 2 mm across The individual crystals commonly enclose grains of iron ore garnet biotite and pyroxene

In the more leucocratic rocks (16), the orthoclase plates tend to be sub parallel as in the syenite pegmatites and are about 2 0 mm x 0 2 mm with smaller prisms of pyroxene or in some cases hornblende interleaved with them The coarser crystals contain a little microperthitic albite in some sections

Remnants of plagioclase are preserved in some of the more lime rich rocks (21 24) The plagioclase occurs as zoned cores to orthoclase crystals and is traversed by fractures that do not extend into the surrounding orthoclase so that frequently the plagioclase inclusions are ragged remnants (Plate IV fig 4) The plagioclase has a refractive index well above that of the orthoclase and is optically positive so that it is probably andesine

Some sections (24 29) contain a mineral that somewhat resembles altered plagioclase It is biaxial and optically positive with a refractive index about that of andesine and a birefringence less than that of orthoclase It tends to occur in more or less rectangular grains with a prominent cleavage at right angles to the longer axis and consistently extinguishes parallel to this cleavage It commonly appears dusty and many grains are more or less altered to a zeolitic substance the alteration developing along the cleavage The low birefringence and the straight extinction do not fit andesine and there is no orthorhombic mineral that has all the requisite optical characters so that the mineral remains indeterminate The untreated mineral is not affected by water soluble dyes like methylene blue, though the straw coloured biotite in one section (29) was rendered reddish violet by immersion in an aqueous solution of this dye

The sphene in the hybrid rocks occurs as coarse crystals up to 2 mm long Occasionally clots of as many as fifty crystals of sphene the individual crystals being about 0 5 mm long have been observed the clots of sphene forming the cores of clots of pyroxene crystals Small crystals of sphene are included in some of the garnet grains and sphene is often intimately associated with areas of intergrown biotite and garnet suggesting that it represents titania set free during the transformation of the pyroxene into these minerals

It may be noted that although sphene occurs in many of the alkali rocks the amount of TiO_2 in the analyses of these rocks rarely exceeds 0 5% This is true also of the potash rich hybrid rocks In the lime rich hybrids however, and in the dolerite, the TiO_2 content is commonly in excess of 1 0% suggesting that the sphene in the lime rich rocks comes largely from the ferromagnesians of the original dolerite

The apatite tends to form equally coarse grained crystals some of which are speckled with black dust like inclusions Most of it, however is clear and colourless It is most abundant in the lime-rich hybrid rocks which contain in excess of 1 0% P_2O_5 as compared with less than 0 5% in most of the potash rich hybrid and dyke rocks and the dolerite The magnetite in the hybrid rocks occurs as equi dimensional grains whose size corresponds to the general grain size of the particular specimen It tends to associate with the biotite-garnet intergrowths and does not occur as inclusions in the pyroxene

Conclusions.

The metamorphic alteration of the dolerite at Regatta Point provides an excellent example of the distinctive behaviour of igneous rocks when subjected to thermal metamorphism, as outlined by Harker (1932, pp 103-110). The first stage is the conversion of a higher mineral (pyroxene) to a lower (hornblende). The dolerite, having cooled rapidly from a high temperature, its pyroxene minerals are in a metastable state. The first effect of slowly rising temperature has been to restore molecular mobility to the rock, and permit these metastable, high temperature minerals to react with their matrix, and transform to hornblende, a mineral stable at the lower temperature induced by the thermal metamorphism. Similarly, the magnetite has reacted to form biotite, whereas the felspar, as is common to such rocks, has proved more stable, and has not recrystallized appreciably. In this initial stage of metamorphism, the minerals have, therefore, undergone the reaction changes that they would normally have undergone if the dolerite magma had cooled slowly. It is "a suspended reaction, which now takes effect when the appropriate temperature is realized".

With advancing metamorphism (in the "transition zone"), this change is reversed. At the higher temperatures now prevailing, augite and not hornblende is the stable mineral.

At this stage, however, reaction with the invading potash-rich magma assumes significant proportions, with the development of hybrid rocks, and the reactions involved provide an illustration of Bowen's (1928, pp. 197-200) conclusions as regards the processes of assimilation and hybridization.

Bowen states (p. 197) that "any magma saturated with a certain member of a reaction series, is effectively supersaturated with all higher members of that reaction series. It cannot . . dissolve inclusions of such higher members, but can only react with them to convert them into that member of the reaction series with which it is saturated." Thus we find the potash-rich magma, which is saturated with soda-rich sanidine felspar, reacting with the plagioclase of the dolerite The soda from the plagioclase can enter the syenitic magma, but the lime from the plagioclase can enter into the sanidine only in small amount, for the magma is saturated with respect to lime minerals The excess lime is precipitated as augite, the lime mineral with which the syenitic magma is saturated The effect is, therefore, simply to promote the normal process of crystallization. It may be noted that the process is somewhat more complicated than is indicated by Bowen's statement quoted above and involves the transference of the lime from one reaction series (the felspars) to another (the ferromagnesian). The soda from the plagioclase is partly taken up by the later felspars, and partly transferred to the pyroxenes Where there has been local precipitation of pyroxene to excess, the residual magma appears to have been "desilicated", and the soda has been reprecipitated partly as nepheline. The alumina from the plagioclase is largely added to the magma, intensifying its tendency to become saturated in this direction

Where the included rock contains minerals later in the reaction series than the minerals with which the magma is saturated, Bowen (p. 200) considers that the included minerals will simply dissolve, with a simultaneous precipitation of the minerals with which the magma is saturated. The hornblende of the metamorphosed dolerite, which is later in the ferromagnesian reaction than the augite of the syenitic magma, was thus under a double compulsion to give place to augite. Increasing intensity of thermal metamorphism drove it in this direction, while the incoming syenitic magma tended to dissolve it when its constituents were reprecipitated as augite It is not surprising therefore that the passage from the metamorphosed dolerite zone to the hybrid zone is one of rapid transition, with no sharp margin Similarly the late reaction of augite to form garnet and biotite as the magma became increasingly saturated in Al_2O_3 is only a repetition on a more pronounced scale of a reaction normal to the (apparently) uncontaminated syenitic magma

These changes bear out Bowen's further conclusion (Bowen 1928, p 223) that magmas may incorporate considerable quantities of foreign inclusions both by the methods of reactive solution and by reactive precipitation All of these actions are however an emphasizing of normal processes possible in the absence of foreign matter This conclusion has significance in any speculation as to the nature of the deeper lying unexposed alkali rocks at Port Cygnet

It is established that the intrusion is a differentiated syenitic stock of which the uppermost zone is presumably from its texture a chilled margin This marginal zone of syenite porphyry closely resembles in chemical composition the banatite that forms the upper part of the Mt Dromedary laccolith in New South Wales The Mt Dromedary laccolith appears to have developed through the differentiation in situ of a monzonitic magma giving rise to an uppermost zone of banatite and lower zones of shonkinite and pyroxenite (approaching jacupirangite)

Assuming that assimilation only emphasises normal processes then the local development of a hybrid rock approximating to a shonkinite at Regatta Point suggests that the trend in the differentiation of the Port Cygnet stock would have been towards the formation of a layer of shonkinite within the stock in addition to the visible upper layer of syenite porphyry resembling banatite Analogy with Mt Dromedary suggests that these rock types are derived from the differentiation of a monzonitic magma

The process of differentiation is at Mt Dromedary involved a concentration of potash in the form of large phenocrysts of sanidine presumably by upward displacement of residual potash enriched magma and possibly by upward flotation of the early formed sanidine crystals The sanidine crystallized side by side with plagioclase felspars rich in soda the two series becoming increasingly incapable of solid solution with one another as the temperature decreased Pronounced fractional crystallization of the sanidine aided the concentration of potash in the residual magma The early formed sanidine crystallized at a temperature which permitted a high degree of solid solution of albite in the sanidine and became armoured about by marginal zones progressively richer in potash which effectively prevented return of soda to the magma as the temperature declined The soda rich cores became increasingly unstable as the temperature declined and finally unmixed to form microperthite

In the later stages of differentiation when considerable crystallization of coarse sanidine crystals had occurred it seems possible that the intrusion of some of the dykes was accompanied by some degree of filter press action This would explain the occurrence of dykes with identical matrices having very variable proportions of sanidine phenocrysts like the tinguaites and especially the syenite aplites and pegmatites

The close chemical resemblance of the leucocratic hybrid rocks at Regatta Point to the more potassic dyke rocks suggests that the dyke rocks are representative of a zone or layer of differentiated rock within the intrusion

The hauyne in the dyke rocks is presumably the equivalent of the nepheline in some of the hybrid rocks

TABLE 1—ANALYSIS OF THE SYENITE PORPHYRY (BANATITE)

—	1	2	A	B	C
SiO_2	61 27	63 10	64 49	61 96	66 04
Al_2O_3	18 59	17 11	17 48	17 07	15 57
Fe_2O_3	1 58	1 04	1 64	2 35	1 91
FeO	2 18	3 02	1 69	3 37	1 94
MgO	0 58	1 15	0 66	1 36	1 41
CaO	4 05	3 65	3 28	3 41	3 50
Na_2O	4 30	3 94	4 16	4 65	3 41
K_2O	4 06	4 64	4 79	3 80	3 72
H_2O + 110	0 42	0 42	0 52	0 93	1 15
H_2O − 110	0 60	0 55	0 18		
CO_2	Nil	0 24	0 71		
TiO_2	1 28	0 82	0 46	0 99	0 50
P_2O_5	0 61	0 30	0 22		0 19
MnO	0 42	0 12	0 11	0 09	0 06
	99 92	100 10	100 89	100 00	100 00

1 Syenite porphyry (No 54) containing hornblende and pyroxene from near the saddle of the road from Lymington to Wattle Grove Port Cygnet district *Analyst* A B EDWARDS

2 Syenite porphyry (No 72) with altered hornblende from Petchey s Bay Port Cygnet district, *Analyst* A B EDWARDS

A Banatite (Syenite) Mt Dromedary laccolith N S W (I A Brown *Proc Linn Soc N S W*, vol 55 Pt 5 p 637 1930)

B Average Akerite (R A Daly Igneous Rocks and the Depths of the Earth p 12)

C Average Quartz Monzonite (R A Daly *Ibid* p 15)

For location of analysed specimens see Fig 2

TABLE 2—ANALYSES OF PORT CYGNET DYKE ROCKS
(Analyst A B Edwards)

—	1	2	A	B	3	4	C	D	E	5	6
SiO_2	58 0	54 70	55 00	56 87	57 75	54 20	55 02	57 46	62 70	61 20	62 90
Al_2O_3	19 81	19 15	20 91	18 21	18 80	20 48	20 42	15 40	16 40	21 90	18 09
Fe_2O_3	1 1	3 65	2 06		6 05	4 90	3 06	4 87	3 34	1 77	0 72
FeO	1 68	1 8	3 73	8 01	0 84	1 28	1 82	0 87	2 35	0 57	1 16
MgO	0 47	0 9	0 63	0 46	1 01	0 40	0 59	1 37	0 9	0 60	0 58
CaO	5 65	5 75	3 22	4 54	2 95	2 85	1 07	2 59	0 96	1 00	3 60
Na_2O	3 95	4 57	2 80	3 36	3 33	4 03	8 03	5 48	7 13	2 20	2 83
K_2O	7 57	7 62	8 66	5 75	9 02	9 30	5 38	9 44	5 25	9 90	8 97
H_2O + 110° C	0 11	0 65	1 87	2 28	0 28	0 42	2 77	0 82	0 70	0 25	0 52
H_2O − 110° C	0 17	0 38			0 42	0 86		0 09		0 65	0 35
CO_2	Nil	Nil	0 38		Nil	Nil		0 13		Nil	Nil
TiO_2	0 32	0 45	0 35		0 10	0 20	0 81	0 60	0 92	tr	0 16
P_2O_5	0 30	0 24	tr		tr	0 50	0 04	0 21		tr	0 09
MnO	0 12	0 21	0 77	2 61	0 25	0 12	0 18	tr	tr	tr	0 06
	100 32	99 44	101 03*	101 09	100 20	99 40	100 00	100 42*	100 53	100 04	100 17

* + 0 61 S   * + do 1 19

1 Hauyne sanidine garnet porphyry (81) quarry near road leading from Regatta Point to Wattle Grove

2 Hauyne sanidine garnet porphyry (110) from road north of Toby s Hill

A Garnet nosean solvsbergite from vicinity of Regatta Point (F P Paul *Tscher Min Petr Mitt*, vol 25 n f 269 318 1906)

B Garnet trachyte on beach between Port Cygnet and Lymington (W A McLeod and O E White *Papers Roy Soc Tas* 1898 99 p 75)

3 Sanidine tinguaite (93) north of jetty northern headland of Copper Alley

4 Tinguaite (95) Mt Mary mine Mt Mary

C Average tinguaite (R A Daly Igneous Rocks and the Depths of the Earth p 27 1933)

D Tinguaite with sanidine phenocrysts Bearpaw Mts Montana (Weed and Pirsson *Am Jour Sci* II p 192 1896)

E Solvsbergite Longethal Norway (Brogger Eruptivgesteine Kr at I p 80 1894)

5 Syenite pegmatite (25) inlet south of Regatta Point

6 Garnet orthoclasite (19) Regatta Point

For location of analysed specimens see Fig 2

TABLE 3—COMPOSITION OF SANIDINE PHENOCRYSTS IN PORT CYGNET ROCKS
(Analyst A B Edwards)

Rock	K_2O	Na_2O	Calculated Composition	Mean Refractive Index
Syenite porphyry (banatite) (54 72)	5 47	4 37	Or39Ab37An30	1 525 ± 003
Sanidine tinguaite (98)	9 60	3 51	Or57Ab29An14	1 525 ± 003
Hauyne-sanidine garnet-porphyry (110), (magpie-rock)	9 66	3 09	Or58Ab26An16	1 525 ± 003
Hauyne sanidine garnet porphyry (116) Livingstone Hill	9 95	3 14	Or59Ab27An14	1 525 ± 003
Sanidine garnet-porphyry (66) (biscuit rock)	12 69	1 84	Or78Ab16An6	1 525 ± 003

TABLE 4—ANALYSES OF METAMORPHOSED DOLERITE AT REGATTA POINT PORT CYGNET
(Analyst A B Edwards)

—	1	2	3	4	5	A	B	C	D	E
SiO_2	54 90	54 30	55 20	55 20	55 20	52 65	55 70	38 39	38 38	48 04
Al_2O_3	13 49	14 01	14 88	15 00	17 28	16 23	17 58	7 05	6 15	17 96
Fe_2O_3	4 40	3 51	3 68	4 24	4 23	0 51	0 73	9 07	11 70	4 31
FeO	6 12	6 89	7 49	5 11	5 90	8 21	9 21	6 17	8 14	5 58
MgO	5 70	5 10	4 27	4 15	4 76	6 64	2 79	11 58	11 47	4 00
CaO	9 65	9 56	9 75	9 95	8 20	11 34	9 40	19 01	18 60	8 89
Na_2O	2 53	1 90	2 22	2 95	1 94	1 68	2 29	0 74	0 78	4 30
K_2O	1 60	1 54	0 99	2 00	1 20	0 90	1 33	0 75	0 13	2 28
H_2O + 110	0 18	0 35	0 65	0 21	0 15	0 48	0 12	0 33	0 54	1 34
H_2O − 110	0 42	0 97	0 12	0 35	0 16	0 85	0 56	0 14	0 18	
CO_2	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0 32	Nil	
TiO_2	0 88	1 35	1 25	1 30	1 32	0 58	0 85	4 94	4 32	1 86
P_2O_5	0 12	0 20	0 06	0 10	0 12	0 01	tr	0 82	0 17	0 65
MnO	0 21	0 17	0 16	0 17	0 15	0 15	0 12	0 32	0 16	0 19
	100 20	99 84	100 62	100 19	100 58	100 13	100 23	*99 89	100 72	100 00

* + do 0 06

1 Slightly metamorphosed dolerite (36) just south of Cygnet jetty Regatta Point
2 Partly uralitized dolerite (1a) midway between Cygnet jetty and Regatta Point
3 Completely uralitized dolerite (7A) north side of Regatta Point
4 Metamorphosed dolerite (11) from the transition zone Regatta Point
5 Dolerite dyke (40) south side of Copper Alley Port Cygnet
A Average undifferentiated Mesozoic dolerite of Tasmania (average of [illegible] analyses) (Edwards *Jour Geol* 50 p 465 1942)
B Differentiated dolerite from 950 feet above sea level Mt Nelson Tasmania (Edwards *Ibid* p 470)
C Jacupirangite Magnet Cove (Washington *Jour Geol* 9 1901 (20 22)
D Jacupirangite Sao Paulo Brazil (Washington *Ibid*)
E Average Essexite (Daly Igneous Rocks and the Depths of the Earth 1933 p 22)
For location of analysed specimen see Fig 4 and Fig ?

TABLE 5—ANALYSES OF ALKALI HYBRID ROCKS AT REGATTA POINT PORT CYGNET
(Analyst A B Edwards)

—	1	2	3	4	A	B	C
SiO_2	65 90	58 10	47 10	49 85	46 30	48 34	48 66
Al_2O_3	19 68	17 37	16 70	8 35	9 87	11 79	12 36
Fe_2O_3	2 78	1 80	4 10	10 96	7 41	2 31	3 08
FeO	2 88	2 16	5 01	4 78	5 40	7 72	5 80
MgO	1 53	1 32	2 52	6 61	7 18	9 59	8 09
CaO	5 85	5 65	9 2	9 25	14 20	12 70	10 46
Na_2O	0 71	2 30	1 90	1 84	1 74	1 60	2 71
K_2O	0 29	8 87	6 61	5 42	3 81	3 17	5 15
H_2O + 110° C	0 32	0 28	0 52	0 67	1 85	0 68	1 46
H_2O − 110° C	0 30	0 43	0 38	0 42		0 04	
CO_2	Nil	Nil	Nil	Nil	n d	tr	
TiO_2	0 48	1 17	1 41	1 08	1 97	0 88	0 97
P_2O_5	0 20	0 10	1 41	1 27	1 01	0 87	1 07
MnO	0 36	0 11	0 21	0 26	tr	0 15	0 13
	99 74	99 61	99 67	99 66	100 22	99 90	100 00

1 Leucocratic hybrid rock (27) or contaminated syenite about 300 yards south of the transition zone (Judge's Box)
2 Leucocratic hybrid rock (14) about 70 yards south of the transition zone (Judge's Box)

3 Melanocratic hybrid rock (24) near the head of the inlet on the south side of Regatta Point, about 250 yards south of the transition zone (Judge's Box)

4 Melanocratic hybrid rock (18), about 150 yards south of the transition zone (Judge's Box)

A. "Monchiquitic nephelinite" (F P Paul *Tscher Mins Petr Mitt* 25, n f, 269 318 1906). This is the 'monchiquitic absarokite' of Twelvetrees

B Shonkinite Tilba Tilba Village Mt Dromedary New South Wales (I A Brown *Proc Linn Soc N S W* 55 (5) 656 1930)

C Average absarokite (Daly Igneous Rocks and the Depths of the Earth 1933 p 23)

For location of analysed specimens see Fig 4

TABLE 6—ANALYSES OF FERROMAGNESIAN MINERALS IN PORT CYGNET ROCKS

(*Anal* A B Edwards)

	Pyroxenes				Hornblendes			Biotite	Garnet	
	1	2	3	A	4	5	6	7	8	B
SiO_2	45 18	48 30	48 72	48 40	39 0	[illegible] 20	48 40	34 2	36 00	36 87
Al_2O_3	6 02	5 14	0 40	6 25	17 4	16 06	12 74	5 9	7 98	7 28
Fe_2O_3	[illegible] 15	[illegible]	4 75	[illegible] 49	9 60	11 42	8 80	10 2	17 07	
FeO	[illegible] 77	6 55	14 40	15 05	11 5[illegible]	8 80	1[illegible] [illegible]4	13 8	4 17	17 12
MgO	8 00	10 16	10 93	14 88	7 60	9 76	6 30	16 0	0 34	12 49
CaO	[illegible]3 25	20 70	13 13	12 70	1[illegible] [illegible]0	1[illegible] [illegible]0	10 90	Nil	28 80	11 98
Na_2O	n d	n d	n d	0 10	n d	1 33	n d	0 9	n d	
K_2O	n d	n d	n d	0 05	n d	1 8[illegible]	n d	10 0	n d	
H_2O	n d	n d	n d	0 [illegible]0	n d	n d	n d	n d	n d	0 29
TiO_2	1 06	0 44	0 60	0 31	0 25	1 39	1 [illegible]5	1 3	1 76	
P_2O_5	Nil	0 04	tr	tr	0 15	0 01	0 1[illegible]	0 5	0 72	
MnO	0 91	0 18	0 09	0 35	0 13	0 72	0 09	tr	1 24	13 68
	100 34	99 01	99 04	99 60	98 42	100 69	98 84	92 8	98 08	99 71

1 Pyroxene (augite) from syenite porphyry dyke Deep Bay

2 Pyroxene (augite) from hybrid rock (18) Regatta Point

3 Composite pyroxene slightly uralitized from the dolerite (3[illegible]) Regatta Point

A Composite pyroxene chilled base of Mt Wellington dolerite sill (Edwards *Jour Geol* vol 50, p 583 194[illegible])

4 Hornblende from syenite porphyry (banatite) dyke Little Oyster Cove

5 Hornblende from hauyne sanidine garnet porphyry dyke (110) Toby's Hill Port Cygnet

6 Hornblende from uralitized dolerite (7) Regatta Point

7 Biotite from leucocratic hybrid or contaminated syenite (30) Regatta Point

8 Andradite Garnet (melanite) from hauyne sanidine garnet porphyry (110) Toby's Hill Port Cygnet

B Johnstonotite garnet from garnet trachyte (hauyne sanidine garnet porphyry) from Copper Alley jetty (White and McLeod) Papers *Roy Soc Tas* 189[illegible] p 75)

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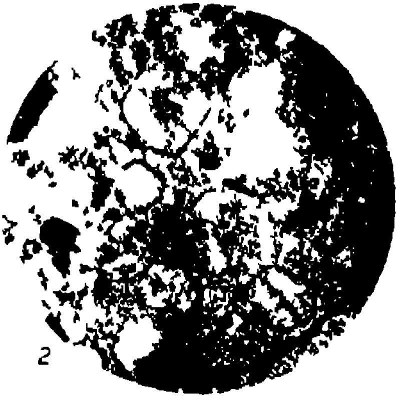

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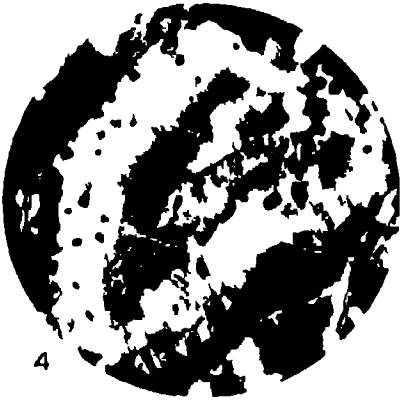

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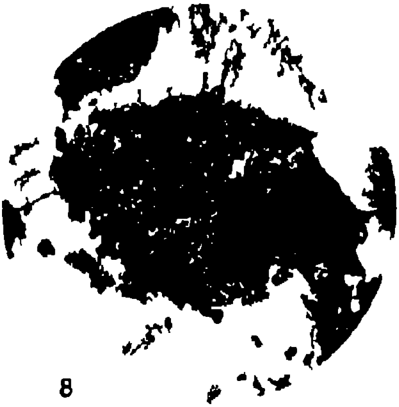

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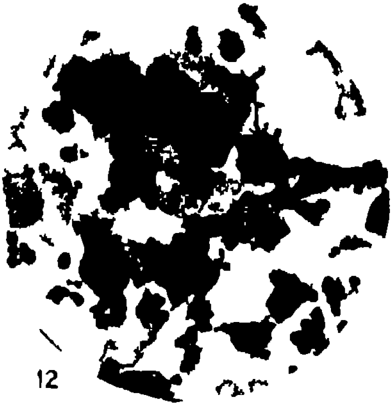

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Illustrations.

PLATE IV

FIG 1—Cluster of zoned melanite garnet in hauyne sanidine garnet porphyry dyke (110) Toby's Hill Ordinary light × 25

FIG 2—Group of altered hauyne crystals showing their characteristic form Hauyne sanidine garnet porphyry (81) near Regatta Point Ordinary light × 35

FIG 3—Zeolite vein cutting and displacing a plate of sanidine in hybrid rock Regatta Point Nicols crossed × 35

FIG 4—Phenocryst of orthoclase enclosing remnants of a large plagioclase crystal (dark) in hybrid rock (24) Regatta Point Nicols crossed × 25

FIG 5—Least altered dolerite (36) showing characteristic texture of intergrown plagioclase and pyroxene Near Cygnet jetty Ordinary light × 35

FIG 6—Thermally metamorphosed dolerite (7A) with pyroxene converted to hornblende, but preserving the texture of the dolerite Regatta Point Ordinary light × 35

PLATE V

FIG 7—Hornblende altering to granular augite in dolerite from the transition zone Regatta Point Ordinary light × 45

FIG 8—Crystal of hornblende completely altered to granular augite and magnetite in dolerite in the transition zone Regatta Point Ordinary light × 45

FIG 9—Pyroxene crystal with a narrow rim of biotite and melanite garnet intergrown with one another Hybrid rock Regatta Point Ordinary light × 40

FIG 10—Advanced stage of alteration of pyroxene (core) to biotite and garnet (margin) Ordinary light × 35

FIG 11—Pseudomorph of biotite and melanite garnet after pyroxene crystal Ordinary light × 35

FIG 12—Hybrid rock with relatively coarse crystals of biotite and melanite garnet dispersed through it Ordinary light × 30

[Proc Roy Soc Victoria 58 (N S) Pts I-II, 1947]

Art X —*The Lagenid Foraminifera and Their Relationships*

By WALTER J PARR F R M S

[Read 13th December 1945]

Abstract.

The writer reviews the opinions currently held as to the position of the lagenid foraminifera and submits evidence to show the close relationship of the genera *Lagena* *Oolina* (with *Entosolenia* as a synonym) *Fissurina* and the hooded forms usually referred by authors to the genus *Ellipsolagena* He regards *Ellipsolagena* as identical with *Fissurina* and erects a new genus *Parafissurina* for the reception of the hooded forms

From the evidence the writer concludes that instead of the lagenid foraminifera being a polyphyletic group of end forms derived from multilocular genera belonging to several families they are not end forms and that all belong to the same family He also does not consider them as was believed by Brady to be ancestral to the multilocular forms of the Nodosariidae and the Polymorphinidae but suggests that the lagenid forms and the multilocular forms had a common ancestor The family Lagenidae is proposed for the unilocular forms with the Nodosariidae restricted to the multilocular forms usually placed in this family

Introduction

During work on the foraminifera extending over more than twenty years the writer has met with from 200 to 300 species of lagenid foraminifera and their identification has led to a consideration of the value of the genera erected by authors for the reception of these forms In submitting the results of these investigations it should be said at the outset that a full understanding of the lagenid foraminifera cannot be obtained until well preserved foraminiferal faunas from the Jurassic and also from the Palaeozoic have been studied as it is in deposits of these ages that we must look for the progenitors of the present day genera It is however hoped that the evidence now to be presented will be sufficient to show that the views which are currently held with regard to the status and relationships of some of the lagenid foraminifera should be revised

Until the publication of Dr J A Cushman's outline of a re classification of the foraminifera in 1927 authors had with few exceptions been content to follow the late Dr H B Brady in referring all of the single chambered hyaline foraminifera to the genus *Lagena* Walker and Boys Cushman limited the use of *Lagena* to those species in which the test was either with or without a neck and the aperture was radiate (rarely) rounded elliptical or slit like and terminal He included within the definition of *Lagena* such genera as *Oolina* d'Orbigny *Amphorina* d'Orbigny *Fissurina* Reuss *Trigonulina* Seguenza and other genera which are now generally accepted as synonymous with *Lagena* For those species with a rounded test and an internal tube free at the inner end and with the aperture centrally situated at the end of the test and elliptical or circular in shape Cushman revived Williamson's genus *Entosolenia* which he transferred from the family Lagenidae to the Buliminidae The third group of lagenid foraminifera recognized by Cushman was referred by him to the genus *Ellipsolagena* A Silvestri which he placed in the family Ellipsoidinidae In this the test has an internal tube at one side of the aperture which is elongate subterminal curved with one side raised into a protecting hood

Several years after the appearance of Cushman's work, Dr. J. J. Galloway (1933) published his book, "A Manual of Foraminifera", in which a different treatment of the lagenid foraminifera was proposed. He recognized eight genera, of which *Balanulina* Rzehak is now known to be a cirripede, and *Obliquina* Seguenza, as an abnormal form with apparently only a single record, need not be considered here. The remaining genera were divided among three families, viz.—

GENUS.	FAMILY.
(1) *Oolina* d'Orbigny (with *Entosolenia* as a synonym)	NODOSARIIDAE (= Lagenidae of Cushman)
(2) *Lagena* Walker and Boys	„
(3) *Amphorina* d'Orbigny	„
(4) *Fissurina* Reuss	„
(5) *Trigonulina* Seguenza	UVIGERINIDAE
(6) *Ellipsolagena* A. Silvestri	PLEUROSTOMELLIDAE (= Ellipsoidinidae of Cushman)

The four genera used by Galloway and not by Cushman are *Oolina, Amphorina, Fissurina,* and *Trigonulina*. *Oolina* has, however, *Entosolenia* as a synonym.

Chapman and the present writer, in their classification of the foraminifera (1936), recognized only two genera, *Lagena* and *Ellipsolagena,* the former being placed in the Nodosariidae and the latter in the Pleurostomellidae. *Lagena* was used in the same sense as by Cushman with the addition of *Entosolenia* as a synonym, as it was considered *Entosolenia* could not be satisfactorily distinguished from *Lagena.*

Here, it may be convenient to give in some detail the published views of the authors named on the origin and relationships of the various genera. Cushman, in the third edition of his Classification (1940) states on page 195 (under the family Lagenidae):—

> "It is rather evident that the forms included under *Lagena* have probably been derived from various sources, and perhaps but a few of them really belong to the family Lagenidae".
>
> P. 203. "It is very doubtful if many of the forms classed as *Lagena* really belong to this genus of this family" (i.e. the Lagenidae).

and on p. 238 (under the family Buliminidae) —

> "*Entosolenia* with its *Bulimina*-like aperture and internal tube probably developed into numerous species now usually called *Lagena*"
>
> P. 238. "*Angulogerina* with its sharply triangular test is triserial, and from it came *Trifarina* which is uniserial in the adult. From this were probably derived those angled "Lagenas" sometimes called *Trigonulina* and *Tetragonulina*"

In every case, Cushman regards the unilocular forms as having evolved from multilocular ones.

Galloway (1933, p. 230 *et seq.*), in his account of the Nodosariidae, discusses at length the relationships of the unilocular foraminifera placed by him in this family. His views are too long to quote in full, but to summarize them, he regards these unilocular genera as end forms derived from multilocular forms. On p. 233, he gives reasons why they should be regarded as neither simple nor ancestral to the multilocular genera of the Nodosariidae, contrary to the belief of Brady and others. *Lagena* and *Amphorina* are considered to be derived from *Dentalina* and *Nodosaria,* while *Fissurina* is regarded as having evolved from *Lingulina*. *Oolina* is considered to have *Glandulina* as an ancestral form.

On p. 372, he states:—

> "*Trigonulina* seems to be the end stage from *Dentalinopsis* or from *Triferina*, and since it is usually monothalamous has heretofore been considered as a synonym of *Lagena*. *Lagena*, as ordinarily defined is a highly polyphyletic group, the end member of several lines of evolution. It may also be that the three-sided forms of single-chambered foraminifera, here referred to *Trigonulina*, were derived from several different families, but if so there is as yet no known way of separating the isomorphs."

On p. 380, Galloway remarks:—

> "In *Ellipsolagena*, the internal chambers have been accelerated out or resorbed much as in the case of *Orbulina*. Whether *Ellipsolagena* was derived from *Ellipsoidina*, which it most nearly resembles, or from *Ellipsobulimina*, or from *Ellipsolingulina*, is not clear. The carinate edge of the test, and particularly the compressed form of some species indicate that *Ellipsolingulina* was the ancestor of *Ellipsolagena* It may be that *Ellipsolagena*, as now understood, embraces the end members of all three genera of the family mentioned as possible ancestors"

Chapman and Parr (1936) and Glaessner (1945) have also treated the lagenid foraminifera as having evolved from multilocular forms, belonging to more than one family

Discussion of the Lagenid Foraminiferal Genera.

Lagena Walker and Boys, *Testacea minuta rariora*, etc., 1784, p. 2

Type species: *Lagena sulcata* Walker and Jacob = *Serpula* (*Lagena*) *sulcata* Walker and Jacob, 1798 = *Serpula* (*Lagena*) *striata sulcata rotunda* Walker and Boys, 1784. Designated by Parker and Jones, 1859

In its typical form, as represented by the genotype, *L sulcata* (Plate VI, fig 1), the test consists of a single almost globular chamber, with the apertural end drawn out into a moderately long neck at the end of which is the circular aperture There is no entosolenian tube.

The wall in species of *Lagena* does not appear to show the variety of ornamentation seen in *Oolina* and *Fissurina*, being either smooth, as in *L. clavata* (d'Orbigny), variously costate, as in *L. sulcata* (W & J), *L. curvilineata* Balkwill and Wright, and other species, or hispid, aculeate, or beaded (as in *L distoma-margaritifera* Parker and Jones). The reticulate ornament and double wall found in some species of *Oolina* and *Fissurina* are not represented, but the neck shows a variety of ornamentation not seen in these two genera, being at times longitudinally or spirally costate or annulated.

Amphorina d'Orbigny, "*Foraminifères*", in: *Dictionnaire universel d'histoire naturelle* Paris, 1849, vol 5, p. 666

Type species: No species named by d'Orbigny. *Amphorina gracilis* Costa. 1856, designated by Cushman, 1928

This genus was erected by d'Orbigny for the reception of those lagenid foraminifera with a fusiform body chamber one end of which is drawn out into a long neck terminating in the circular aperture The genotype, designated by Cushman, is *A. gracilis* Costa (Plate VI., fig. 3), but better-known examples of this generic type are *Lagena distoma* Parker and Jones and *L. distoma-margaritifera* Parker and Jones. The genus differs only from *Lagena* in having the aboral end tapering to a point instead of having the end rounded as in *Lagenae* of the *L. sulcata* group. The forms with rounded tests intergrade with those of the *Amphorina* type to such an extent that it is not possible to draw a dividing line between the two Structurally the two genera cannot therefore be separated and the writer accordingly agrees with Cushman that the *Amphorina* forms should be included under *Lagena*

Oolina d Orbigny *Voyage dans l Amérique méridionale Foraminifères* Strasbourg Levrault 1839 vol 5 pt 5 p 18

Type species *Oolina laevigata* d Orbigny 1839 Designated by Galloway and Wissler 1927

For some unknown reason the genus *Lagena* was never used by d Orbigny although it had been recognized by two other French authors Defrance and Deshayes before the genus *Oolina* was erected *Oolina* as described by d Orbigny includes forms of *Lagena Fissurina* and *Oolina* as now understood The genotype of *Oolina O laevigata* d Orbigny (Plate VI, fig 5) was first designated by Galloway and Wissler in 1927 Although d Orbigny states that the test of this species is very transparent he makes no reference to an internal tube which if present should have been readily recognizable As it is not visible in his figure the position of *Oolina* would be doubtful but for the information given by Heron Allen and Earland in their work on the foraminifera of the Ice Free Area of the Falkland Islands and Adjacent Seas (1932 p 361 pl 10 fig 4) They did not find the type specimen of *O laevigata* from the Falkland Islands but record that there is another specimen from the same area in d Orbigny s collection labelled *Oolina laevigata* This they consider to be the same as *Lagena globosa* (Montagu) Another specimen from their own material from the Falklands is figured by them and is very similar to d Orbigny s type figure As the entosolenian tube is visible in their figure there appears no doubt that *O laevigata* belongs to the group of lagenid foraminifera for which Williamson later proposed the name of *Entosolenia* *Oolina* is accordingly regarded as a valid genus with *Entosolenia* as a synonym

The test of *Oolina* in most species is spherical or ovoid and the wall may be smooth as in *O laevigata* d Orbigny costate as in *O costata* (Williamson) or reticulated as in *O hexagona* (Williamson) and *O squamosa* (Montagu) In one species *O hertwigiana* (Brady) the wall is double and on both the outside and inside surfaces of the test it is conspicuously perforated

The aperture in *O lina* is typically a centrally placed rounded terminal orifice which opens internally into an entosolenian tube In the genotype *O laevigata* it is at the end of a very short neck In one species *O globosa* (Montagu) it may be rounded ovate slit like triradiate cruciform or radiate (*vide* Brady 1884 p 441 text figs 11*a g*), but such variation is not typical of *O globosa* as it usually occurs The aperture in this species is generally a rounded opening but is not infrequently stellate The stellate aperture is found in fossil examples of *O globosa* from the Miocene of Victoria and may occur earlier With the exception of *O globosa* all species of *Oolina* have in the writer s experience constantly a rounded aperture

Another feature which is found in *O globosa* and its costate variant *O lineata* (Williamson) is the occasional development of an ectosolenian tube This is not an extension of the body chamber of the same character as the neck of *Lagena sulcata* but is merely a prolongation of the outer end of the internal tube It has been well figured by Wiesner (1931 pl 18 fig 215) from the Antarctic where the writer has met with similar examples Brady (*loc supra cit*) has also figured several examples of *O globosa* from the Irish Sea showing the same form of structure The ectosolenian tube is rather irregular in form and in one of the specimens figured by Brady (Plate VI fig 4) the outer end of the tube is bifurcated. Balkwill and Wright (1885, p 336) note that *O lineata* frequently bears an external tube which is often bent and irregular in shape They figure (*loc cit* pl 14 fig 14) a specimen showing a straight annulated tube

In one species of *Oolina* Brady s *Lagena hertwigiana* there is a short internal tube and a delicate ectosolenian neck The shape of the neck, its diameter which is the same as that of the internal tube and the abrupt manner in which it rises from the apex of the test suggest that it is merely an extension of the internal tube of the same nature as that seen in *O globosa* and *O lineata*

One species of *Oolina* Cushman s *Lagena collaris* (Plate VI fig 6) from the North Pacific has an apertural chamberlet from the base of which and not from the exterior opening the internal tube commences Sidebottom (1912 p 380 pl 14 figs 7 8) in his paper on the Lagenae of the South West Pacific has figured under the name of *Lagena globosa* (Montagu) bilocular forms two specimens which have a very small second chamber In fig 7 the entosolenian tube is as in *L collaris* found only in the initial chamber but in fig 8 each chamber has an entosolenian tube Mr Arthur Earland has sent me a slide containing three specimens of the same form as Sidebottom s and in each of these the entosolenian tube is developed only in the first chamber While an apertural chamberlet is commonly found in the multilocular forms of the Nodosariidae and in the Polymorphinidae the records now given appear to be the only evidence of a somewhat similar structure in the lagenid foraminifera

There are several described species which are probably referable to *Oolina* although the apertural end of the test is drawn out to form a neck resembling that seen in *Lagena* Two of these Brady s *Lagena stelligera* and Heron Allen and Earland s *L scotti* are Recent forms and two others are the Tertiary species figured by Silvestri (1912 p 153 text figs 18-22) under the names of *L strumosa* Reuss var *schlichti* Silvestri and *L hystrix* Reuss (Plate VI fig 7) These four forms all have an internal tube The writer has also met with a smooth entosolenian species like *O globosa* with however a short neck in the Upper Cretaceous of Dandarragan, Western Australia Another fossil species with a produced neck in addition to a probably entosolenian tube is described by Macfadyen (1941 p 63, pl 4 fig (3) under the name of *Lagena daroui* from the uppermost beds of the Lower Lias of England Macfadyen was not able to satisfy himself beyond doubt of the presence of the internal tube but it is not unlikely that the Mesozoic species showing the external characters of the genus *Lagena* include a number in which the entosolenian tube is also present As will be seen later the apertural end of the test in many species of *Fissurina* is similarly extended and the same development is to be expected in *Oolina* which differs only from *Fissurina* in having the test rounded in transverse section instead of being compressed

Entosolenia Williamson Ann Mag Nat Hist ser 2 vol 1 1848 p 5

Type species *Entosolenia lineata* Williamson 1848

This genus is regarded as a synonym of *Oolina* d Orbigny 1839 (*q v*)

Fissurina Reuss Denkschr k Akad Wiss Wien Math—Nat Cl, vol 1 1850 p 366

Type species *Fissurina laevigata* Reuss 1850 (Plate VI fig 8) Monotypic

The characteristics of this genus in its typical form are a compressed, subglobular test with a terminal fissure like cavity which is deepest at the centre where is situated the rounded aperture Internally the aperture is extended into a straight tubular process directed into the centre of the body cavity Apart from the variations in the nature of the surface ornament and the amount of inflation of the test the apertural end in many species tends to be drawn out into a neck and the outer margin of the aperture then loses its slit like shape becoming oval or even circular in outline These forms constitute Seguenza's subgenus Produttine" (*vide* Seguenza 1862 p 53) A well known species exemplifying the *Fissurinae* with a short apertural neck and oval aperture is Brady's *Lagena clathrata* Representatives of those species of *Fissurina* with an elongated neck and circular aperture are Williamson's *Entosolenia lagenoides* (Plate VI, fig 15) and the forms figured by Brady in the Challenger' Report under the name of *Lagena formosa* Schwager In one species of *Fissurina*, Hada's *Lagena curta* (Plate VI fig 14) the aperture is radiate

The species of *Fissurina* have received closer attention from Seguenza (1862) than any other author In addition to the Produttine already mentioned he recognizes two other groups Fissurine and Tubuline The Fissurine and Produttine comprise respectively the forms with the typical aperture of *Fissurina* and those with the apertural end extended into a neck in none of which he had observed the presence of an internal tube Those forms with an internal tube were referred by him to the Tubuline which embraces species with the external apertural characters of both his Fissurine and his Produttine Despite this division of the genus into species with an internal tube and those without it the writer has never met with a species of *Fissurina* in which the internal tube was not present Individual specimens may occur from which for some unknown reason the tube is missing but they are always associated with other specimens of the same species showing the typical characters of *Fissurina* The tube in some species e g *F clathrata* (Brady) is very short but generally it extends well down the centre of the body chamber Although usually straight it may as in *F lispinosa* (Hada) and other species be curved back towards the margin of the chamber and is occasionally S shaped or twisted like a corkscrew towards one side of the test

In other species e g the form figured by Brady (1884 pl 59 figs 8 11) as *Lagena staphyllearia* (Schwager) the tube instead of being centrally placed is directed to one side following the curve of the chamber wall along a line midway between the margins of the test This departure from the usual position of the entosolenian tube is considered to be the first step in the transition from *Fissurina* to *Parafissurina* in which the tube typically occupies this position Mr Earland has pointed out to me that in forms in which the tube occupies this position it is frequently attached to the wall of the chamber and is then semi circular in section, the chamber wall forming the flat side This has been described by Sidebottom (1912, p 406) In the species recorded by Brady (*loc supra cit*) as *Lagena staphyllearia* (Schwager) the tube is free and circular in section at first then becoming attached and semicircular in section in its later half (Plate VII fig 3)

Another direction in which *Fissurina* varies is in the shape of the body chamber The amount of compression may be so slight, as in *F stewartii* (J. Wright), that the test is oval in transverse section but in most species the test is compressed to such an extent that it is distinctly carinate. Up to as many as seven or more marginal keels may be developed, and in some species, e.g., *F. formosa* (Schwager), the keel may be tubulated. The surface of the chamber may be smooth, e.g., *F. laevigata* Reuss; longitudinally costate, e.g., *F. clathrata* (Brady); beaded, e.g., *F. castrensis* (Schwager); pitted, e.g., *F. lacunata* (Burrows and Holland); reticulate, e.g., *F. squamoso-sulcata* (Parker and Jones); or with costae (Mr. Earland informs me these are actually tubules in the wall) radiating from a more or less central point, e.g., *F. radiato-marginata* (Parker and Jones) (Plate VI., fig. 11).

Species of *Fissurina*, e.g., *F. pulchella* (Brady), *F. orbignyana* Seguenza (Plate VI., figs. 12, 13), and *F. lagenoides* (Williamson), show a tendency to develop trigonal and tetragonal forms, some of which have been figured and described as new species by Balkwill and Millett (1884) in their paper on the foraminifera of Galway. In a later paper Balkwill and Wright (1885, p. 341) abandoned this view as to the status of these forms, remarking that trigonal examples of nearly all the British depressed Lagenae had been found by them. Seguenza's genus *Trigonulina* is clearly based on trigonal forms of this nature. While these trigonal and tetragonal forms are generally associated with the normal form and are therefore not true species, there is one species in which the trigonal form is almost constant. This is the Antarctic species described by Wiesner (1931, p. 121, pl. 19, fig. 230) under the name of *Lagena texta* (Plate VII., fig. 2). It has the most highly developed test of all the *Fissurinae*. Quoting Earland's excellent description of the wall structure (Earland, 1934, p. 165), "The three facial surfaces are slightly convex and double walled, the stout internal wall being covered by low ramifying costae, over which is a delicate and hyaline outer shell. The spaces between the costae form cellules, irregularly fusiform in shape, like the pulp cells of an orange." No other species of *Fissurina* known to me has a double wall. Neither Wiesner nor Earland records the presence of an internal tube, although it should be noted that Wiesner placed the species in the sub-genus *Entosolenia*. However, on breaking open specimens, the writer found that the species has an internal tube. The tube, which is straight, slender, and slightly bell-mouthed at the inner end, extends centrally into the chamber cavity for about one quarter of the length of the latter.

Several other species may be referred to here. Three of these, *Lagena cymbula* Heron-Allen and Earland (Plate VII., fig. 1), *L. cymbaeformis* Millett, and *L. depressa* Chaster, all have a depressed oval test, with an internal tube which passes down the median line of one of the longer sides of the test. The aperture is either round or oval. Like Joseph Wright's *Lagena stewartii*, these species all connect *Oolina* with *Fissurina*, but in view of the slight lateral compression of the test and the position of the internal tube, they are perhaps best referred to *Fissurina*, although they are far from typical of this genus. The other form, *Lagena stelligera* Brady var. *nelsoni*, described by Heron-Allen and Earland (1922, p. 148, pl. 5, figs. 20-22) from the Antarctic, is one of the most abnormal of all of the lagenid foraminifera. The aperture is directed to one side of the irregular compressed oval test and there is a long S-shaped internal tube extending almost to the base of the test, which is encircled by a collar-like keel. While the form might be regarded as an asymmetrical *Oolina*, it is probably nearer Brady's *Lagena fimbriata* than to any other species and is accordingly here referred to *Fissurina*. Very similar forms not yet described occur in the Early Tertiary of Victoria.

While *Fissurina* has been neglected by most authors, it appears to be the most important of all of the lagenid genera, its variety of forms and ornamentation showing a greater development than any other genus of the foraminifera. It is also represented by a larger number of well-defined species than any other lagenid genus.

Trigonulina Seguenza, *Dei terreni Terziari del distretto di Messina; Parte II.—Descrizione dei foraminiferi monotalamici delle marne mioceniche del distretto di Messina.* Messina, 1862, p. 74.

Type species: Not designated. *Trigonulina oblonga* Seguenza, 1862, first species, designated by Cushman, 1928 (Plate VI., fig. 16).

This genus is regarded as a synonym of *Fissurina*, *q.v.*

Ellipsolagena A. Silvestri, Mem. Pont. Acc Romana Nuovi Lincei, ser. 2, vol. 6. 1923, pp. 265, 268.

Type species: *Ellipsolagena acutissima* (Fornasini) = *Lagena acutissima* Fornasini, 1890 (Plate VII., fig. 5). Monotypic.

The characters of *Ellipsolagena*, as it is understood by most authors, are a monothalamous test, with an internal tube directed backwards from the aperture which is elongate, subterminal, curved, with one side raised into a protecting hood. While *Lagena ventricosa* Silvestri was designated the genotype by Cushman (1928, p. 265) and this was accepted by Galloway, it was apparently overlooked by both authors that Silvestri, in the paper in which he named *Ellipsolagena*, had referred *Lagena acutissima* Fornasini to the genus No description of the genus was given by Silvestri in the body of the paper, but on page 268, in his explanation of the plate, he describes Fig. 13 as follows:—

"*Lagena acutissima* Fornasini (1890, Mem. R. Acc Sci. Bologna, ser. 4A, vol X, page 466, tavola, fig. 2, 2A) = *Ellipsolagena acutissima* (Fornasini) . . "

As *L acutissima* is the only species mentioned, it is necessarily the genotype and its characters determine those of the genus. Unfortunately Silvestri had not copied Fornasini's figure of the aperture of *L acutissima* correctly, as he shows it to be slightly arcuate, while in Fornasini's drawing it is an elongated oval Fornasini's figures in the 1890 paper (Plate VII., fig. 5) (he figured only the front view of what is unquestionably the same form in his original description of *L. acutissima* and in neither case described the aperture) show the species to be a *Fissurina*-like form without any sign of the hooded aperture found in *Ellipsolagena*, as this genus is usually understood. The absence of any reference in Silvestri's paper to his own earlier species, *Lagena ventricosa* (text-fig. 1) and *Fissurina schlichti* (Plate VII., fig. 6), both of which have a hooded aperture, suggests that he may not have considered them to be *Ellipsolagenae*. It will also be noted that the genera included by him in the family Ellipsoidinidae (*vide* p. 265 of the paper) do not include *Pleurostomella* or any other genera with hooded apertures. This probably gives the reason why he omitted mentioning *Lagena ventricosa* and *Fissurina schlichti*. In the circumstances, there appears to be no alternative but to regard *Ellipsolagena* as a synonym of *Fissurina* and to erect a new genus for the hooded lagenid forms. For this genus, the name of *Parafissurina* is proposed.

PARAFISSURINA, gen nov.

Test calcareous, perforate, consisting of a single, usually compressed, chamber, with an internal tube directed backwards from the sub-terminal aperture, which is an arched or crescentic opening facing the front under a hood-like extension of the ventral wall of the test

Type species *Lagena ventricosa* A Silvestri, 1904 (text-fig 1).

Both Cushman and Galloway, and in this they were followed by Chapman and Parr, regard the hooded lagenid species as being unrelated to the nodosarian forms and group *Ellipsolagena* with *Ellipsoidina, Pleurostomella,* and similar genera of which they consider it an end form In the writer's view, based on the examination of examples of a large number of species, this is incorrect and he regards the hooded forms as a development from *Fissurina*

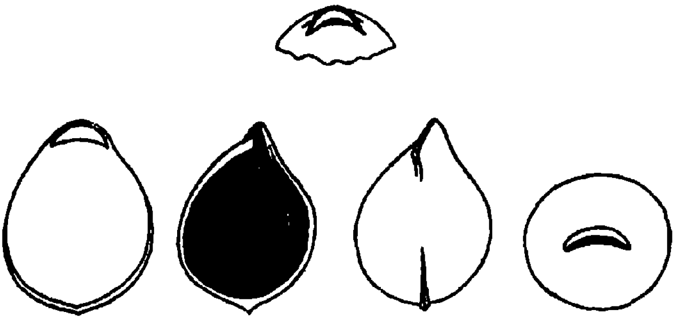

Fig 1 —*Parafissurina ventricosa* (A Silvestri) Genotype of *Parafissurina* gen nov After type figures

As has already been pointed out the first indication of the development of *Parafissurina* from *Fissurina* is the alteration of the position of the entosolenian tube from the centre of the body chamber to a point midway between the margins of the test along one side of the test When this is observed the aperture should be examined from the side when it will be found that in some specimens particularly of the species figured by Brady (1884 pl 59 figs 8 11) under the name of *Lagena staphyllearia* (Schwager) the apertural margin on the side of the test under which the internal tube extends is slightly higher than the opposite edge to the aperture (Plate VII, fig 3) *Ellipsolagena mauricensis* Howe and Roberts (Plate VII fig 4) also shows this structure The difference in height between the two edges is sometimes so slight as to be barely perceptible In these forms the aperture is a straight fissure but in others e g *Fissurina biconica* Silvestri (Plate VII fig 8) and *F obtusa* Egger there is apparently no difference in the height of the rim to the aperture but the aperture itself is arcuate in shape From this point the apertural characters develop along several lines The margin of the aperture on what may now be referred to as the ventral side of the test increases in height and inclines forward till it forms a pronounced hood which may as in Wright s *Lagena marginata* (Walker and Boys) var *inaequilateralis* (Plate VII, fig 7) and Chaster s *L milletti* (Plate VII, fig 9), completely surround the aperture The aperture itself becomes crescentic (as in *Lagena ventricosa* Silvestri) when seen from above and then develops into an arched opening (*Ellipsolagena dorbignyana* Wiesner and other species) finally becoming circular as in *Lagena milletti* Chaster Where the hooded opening is large, as in *Ellipsolagena marginata* Wiesner, a plate is developed which nearly fills the opening, leaving the aperture a curved fissure between the plate and the overhanging hood The description of the aperture as so far given refers to the external appearance of the apertural cavity (the Mundungsnische of Wiesner)

The aperture itself, like that of *Fissurina* is situated at the base of the cavity and is a rounded opening from which the entosolenian tube extends into the interior of the test

Except that the entosolenian tube in *Parafissurina* is curved to conform to the shape of the side of the test on which it rests it is exactly similar to that found in *Oolina* and most species of *Fissurina* viz a narrow tube of even diameter throughout usually becoming somewhat bell shaped at the lower end No structure of this form is found in any genus of the Ellipsoidinidae or in any families other than the Nodosariidae and the Polymorphinidae and there accordingly appears to be no doubt that the relationships of *Parafissurina* are with *Oolina* and *Fissurina* and not elsewhere

The test in species of *Parafissurina* does not develop the variety of ornamentation seen in *Fissurina* Most species have a single encircling keel but an undescribed species from the Tertiary of Victoria has two keels and in Wiesner's *Ellipsolagena dorbignyana* from the Antarctic there are three In *P lateralis* (Cushman) *P cor* (Wiesner) and some other species the test is compressed but the margins are rounded Species with costate pitted beaded or reticulated faces which occur in *Fissurina* do not appear to have been recorded if we except the costate *Ellipsolagena sculpturata* Cushman and Bermudez the generic position of which is doubtful

Apart from the Eocene species *Ellipsolagena mauricensis* Howe and Roberts which is not a typical *Parafissurina* the earliest satisfactory published records of the genus are from the Miocene The writer has however met with a species of the normal hooded type in the Upper Middle Eocene (Bortonian) of New Zealand and several species occur in beds of Upper Eocene or Lower Oligocene age in Victoria

As there are several anomalous lagenid foraminifera which are considered to be species of *Parafissurina* it may be desirable to give a list of the forms now referred to the genus This comprises only those known to the writer and is therefore probably incomplete The forms using the generic specific and varietal names under which they were originally described are *Ellipsolagena bidens* Cushman *E ovata* Wiesner *E marginata* Wiesner *E immersa* Wiesner *E fusiformis* Wiesner *E lata* Wiesner *E cor* Wiesner *E dorbignyana* Wiesner *E fijiensis* Cushman *E cucullata* Chapman and Parr *E* (?) *mauricensis* Howe and Roberts *Fissurina schlichti* A Silvestri *F biconica* A Silvestri *F obtusa* Egger *Lagena ventricosa* A Silvestri *L lateralis* Cushman *L marginata* (Walker and Boys) var *armata* Sidebottom *L marginata* (Walker and Boys) var *inaequilateralis* J Wright *L inaequilateralis* Wright var *semimarginata* Sidebottom *L millettii* Chaster *L elcockiana* Millett (Plate VII figs 10 11) *L invaginata* Sidebottom *L irregularis* Sidebottom *L reniformis* Sidebottom and its variety *spinigera* Sidebottom and *L unguis* Heron Allen and Earland Reference to Sidebottom's papers on the Lagenae of the South West Pacific (1912 1913) will show that he figured a number of other hooded forms but identified them with previously described species in which the aperture is typically fissurine These hooded forms require describing as new species

To sum up the conclusions so far reached the writer recognizes *Lagena* *Oolina* and *Fissurina* as valid genera *Entosolenia* is regarded as a synonym of *Oolina*, and *Ellipsolagena* of *Fissurina* A new genus *Parafissurina* is erected for the reception of the hooded lagenid species hitherto referred to *Ellipsolagena*

The Relationships of the Genera.

The earliest true lagenid foraminifera appear in the Jurassic, in which they are of comparatively rare occurrence. From the Lias of Germany, Franke (1936) has recorded a number of species under the names of *Lagena vulgaris* Will., *L. globosa* Walker, *L. stutzeri* Franke, *L. clavata* d'Orb., *L. ovata* (Terquem), *L. urnula* Franke, *L. mucronata* Terq. and Berthelin, *L. oxystoma* Reuss, and *L. tenuicostata* Franke. Terquem and Berthelin (1875) have recorded *L. ovata* Terq., *L. acicularis* Terq., *L. simplex* Terq., *L. vulgaris* Will., *L. clavata* Reuss, *L. mucronata* Terq. and Berth., *L. hispida* Reuss, *L. aspera* Reuss, and *L. laticosta* Terq. and Berth., from the Middle Lias of France With the exception of *L. stutzeri* (Plate VI., fig. 9), which is compressed and without an apertural neck, these species are all forms in which the test is circular in transverse section. They include typical *Lagenae*, a number of which are of the amphorine type, and apparently also species of *Oolina*, although it is not stated that an internal tube has been recognized in any of the specimens. Undoubted *Oolinae* are, however, known to occur in the Jurassic, as Haeusler (1887, p. 181) records and figures under the name of *Lagena globosa* Montagu specimens showing the internal tube from the Upper Lias of Switzerland.

The presence of true *Fissurinae* in the Jurassic is not so well established, as, while *Lagena stutzeri* Franke and *L. compressula* Gümbel (Plate VI., fig. 10) have the external characters of *Fissurina*, no statement of the existence of an internal tube in these species has been made. When we come to the Lower Cretaceous, the species of lagenid foraminifera are in general form much like those from the Jurassic, although more varied. Haeusler (1887, pl. 4, fig 53) has figured under the name of *Lagena marginata* Montagu a compressed, carinate form from the Neocomian of Switzerland which in external features is a typical species of *Fissurina*. Chapman (1893, pl. 8, figs. 1-16), in his work on the Gault of Folkestone, figures from the Albian a number of species which include true *Lagenae*, as well as what may be forms of *Oolina* and *Fissurina* (recorded as *Lagena marginata* Walker and Boys). The internal characters of these species are not however described, and it is not until the Upper Cretaceous that one finds undoubted *Fissurinae* of similar types to those which are so common in Tertiary and Recent deposits. As has already been stated in the notes on *Parafissurina*, this genus makes its appearance in the Eocene All four genera occur in many forms in the Tertiary and have a world-wide distribution in Recent seas in which they reach their greatest development. In the Tertiary of Victoria they are exceptionally well represented, over one hundred species occurring at one locality, Balcombe Bay, in beds of Miocene age.

From the evidence available, there can be no doubt that *Lagena* and *Oolina* both appear at least as far back as the Lias and that forms with the external characters of *Fissurina* are also present in the early Jurassic. It also appears probably that *Fissurina* came from *Oolina* in the Jurassic by the compression of the test and the consequent development of an aperture adapted to the requirements of a test of this shape. For reasons which are given in the notes on *Parafissurina*, it is considered that the hooded lagenid forms were derived from *Fissurina* and that they have no relationship to the Pleurostomellidae. It is however more difficult to demonstrate satisfactorily the relationship between these entosolenian genera and *Lagena*. There is some evidence which may indicate that the entosolenian forms belong to the same family as *Lagena*. In several genera of the Nodosariidae and also of the Polymorphinidae, multicamerate forms occur which have developed the internal tube. Brady (1884, p. 443) records its presence in Recent species which he identifies as *Nodosaria calomorpha* Reuss, *Polymorphina angusta* Egger, and *P. lanceolata* Reuss, and the writer has also observed an internal tube in the genera *Glandulina* and *Sigmomorphina*. There are also the peculiar minute forms with a fissurine aperture and entosolenian tube described under the names of *Frondicularia translucens* Heron-Allen and Earland, *Lingulina armata* Sidebottom, *L. carinata* d'Orbigny, var. *biloculi* J. Wright, *L. falcata* Heron-Allen and Earland, *L. quadrata* Heron-Allen and Earland, and *L. translucida* Heron-Allen and Earland. A slit-like aperture, resembling that of *Fissurina*, but without the internal tube, is found in typical species of *Lingulina*, in *Gonatosphaera*, and in an undescribed Victorian early Tertiary species otherwise like *Globulina*, and Dr. M. F Glaessner has a species from the Pliocene of Papua resembling in form *Guttulina* but with a slit-like aperture.

It might be suggested that none of these species or genera belongs to the Nodosariidae or the Polymorphinidae, although, on their general form, it would be difficult to place them elsewhere. On the other hand, structures comparable with the fissurine apertures and the internal tube are not known in any other family of the foraminifera. It is true that in some species of *Siphogenerina* there is an internal tube, but this is of a different type from that seen in the entosolenian forms under discussion, being much wider and extending from the top to the bottom of each chamber, while the short phialine apertural neck of this genus is unlike any aperture found in the Nodosariidae or the Polymorphinidae

As apertural characters of the types found in *Lagena, Oolina,* and *Fissurina* all occur in species of the multicamerate genera of the Nodosariidae, there can be little doubt of the relationship of *Oolina* and *Fissurina,* and also *Parafissurina,* to *Lagena* and to the polythalamous Nodosariidae.

Whether the lagenid genera should be regarded as end forms derived from the multilocular genera of the Nodosariidae now needs to be considered. While it has been stated by authors that the lageniform foraminifera are end forms developed from polythalamous genera, there is, in the writer's view, nothing to support this. If this were correct, one would expect that, among the hundreds of species of lagenid foraminifera, microspheric examples would have occurred showing more than one chamber. No one has, however, to the writer's knowledge, ever recorded a microspheric specimen of any of these species. It might be suggested that they have been found and referred to one of the multilocular genera, but this is unlikely as the external characters of most species of the lagenid genera are sufficiently distinct to enable the microspheric form, even if multilocular, to be associated with the megalospheric form. There is, of course, the possibility that, as in some other genera of the foraminifera, microspheric forms apparently do not occur in the lagenid foraminifera. However, in the absence of microspheric multilocular specimens, there is no direct evidence that these single-chambered forms were derived from multilocular forms, the view that the latter were ancestral to the former being based on apparent similarities in form, ornament, and apertural characters. The writer considers it more likely that the lagenid foraminifera, while undoubtedly closely related to the polythalamous genera of the Nodosariidae and the Polymorphinidae, have not evolved from them, but had a single-chambered ancestor. What this ancestor was is unknown but it may have been either a chitinous form or, perhaps, the Palaeozoic genus *Archaelagena* Howchin, which in many respects is close to *Lagena*. Whether the multilocular Nodosariidae were derived from *Lagena, Oolina,* and *Fissurina,* or came directly from the same ancestor as these genera cannot be stated in our existing state of knowledge. Although well-developed multilocular genera of the Nodosariidae occur in the Permian, there does not appear to be any satisfactory record of *Lagena*, *Oolina*, or *Fissurina* from the Palaeozoic. *Archaelagena* is known from the Carboniferous, and Chapman (1900) has recorded from the Upper Cambrian of England under the name of *Lagena* a single-chambered foraminifer the wall structure of which is uncertain, but which is possibly chitinous.

The exact relationship of the lagenid foraminifera to the polythalamous Nodosariidae is therefore uncertain, but the high degree of ornamentation found in the older genera, particularly *Oolina* and *Fissurina*, which is in advance of anything seen in the multilocular forms, as well as the specialized apertures, best developed in *Fissurina* and *Parafissurina*, indicate a different line of development. It is accordingly suggested that the four genera which have been described should be grouped in a separate family, the Lagenidae, and that the family Nodosariidae should comprise only those polythalamous forms which have hitherto formed only part of this family. The superfamily Lagenidea recently proposed by Glaessner (1945, p. 126) will then embrace those two families and the Polymorphinidae. A description of the Lagenidae, with a key to the genera of the family, follows:—

> Family Lagenidae.—Test calcareous, perforate, consisting of a single rounded or compressed chamber with or without an apertural neck; aperture terminal or sub-terminal, variously formed, rounded, stellate, radiate, elliptical, slit-like, or an arched opening directed to one side under an overhanging hood.

Key to Family Lagenidae.

I Test with terminal aperture—	
A. With apertural neck and without entosolenian tube ..	*Lagena.*
B With entosolenian tube and without or with apertural neck—	
(1) Test circular in transverse section ..	*Oolina.*
(2) Test compressed	*Fissurina.*
II. Test with sub-terminal aperture and entosolenian tube ..	*Parafissurina.*

In conclusion, the writer realizes that the genera he has recognized could justifiably be subdivided into a larger number of genera Mr Earland has pointed out to me that the double wall seen in some species, e.g., Wiesner's *Lagena texta*, Brady's *L. hertwigiana*, and Heron-Allen and Earland's *L. scotti*; the marginal tubes in species such as Williamson's *Entosolenia lagenoides* and *E. marginata* var. *ornata*, and Schwager's *Lagena formosa*; and the development of horizontal tubules on the surface, as in Parker and Jones' *L. radiato-marginata*, are all much more radical differences from the presumably original form, a simple globose test, than the differences on which *Oolina*, *Lagena*, *Fissurina* and *Parafissurina* are separated. The purpose of these notes has, however, been to deal with the status, and more particularly, the relationships of known genera, leaving the description of new genera to other workers.

Acknowledgments.

The writer gratefully acknowledges his obligation to his friends, Mr. Arthur Earland, F.R.M.S., and Dr. Martin F. Glaessner, who have both read the manuscript and whose criticism has been largely responsible for the final form of this paper. To Mr. Earland, whose experience of the lagenid foraminifera is unequalled, he is still further indebted for a slide

of over 1,000 specimens of these forms selected by him from the material he has examined during work on the foraminifera extending over a period of nearly sixty years Mr Earland has also kindly sent another slide of specimens from the South West Pacific mounted by the late Mr W Blundell Thornhill whose main collection of these forms from the same area was described by Henry Sidebottom in the Journal of the Quekett Microscopical Club for 1912 and 1913

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Explanation of the Plates.

Plate VI

Fig 1—*Lagena sulcata* (Walker and Jacob) Genotype of *Lagena*. After type figure

Fig 2—*Lagena laevis* (Montagu) After Fornasini 1890

Fig 3—*Lagena gracilis* (Costa) Genotype of *Amphorina* After type figure

Fig 4 *Oolina globosa* (Montagu) Section of specimen showing bifurcated tubular extension of aperture After Brady 1884

Fig 5—*Oolina laevigata* d Orbigny Genotype of *Oolina* After Heron Allen and Earland 1932

Fig 6—*Oolina collaris* (Cushman) After Cushman 1913

Fig 7—*Oolina hystrix* (Reuss) After A Silvestri 1912

Fig 8a b—*Fissurina laevigata* Reuss Genotype of *Fissurina* After type figures

Fig 9a c—*Fissurina stutzeri* (Franke) After type figures

Fig 10a c—*Fissurina compressula* (Gumbel) After type figures

Fig 11a b—*Fissurina radiato marginata* (Parker and Jones) After Brady 1884

Fig 12a b *Fissurina orbignyana* Seguenza After type figures

Fig 13a b—*Fissurina orbignyana* Seguenza Trigonal form = *Lagena trigono orbignyana* Balkwill and Millett 1884 After Balkwill and Millett

Fig 14a b *Fissurina curta* (Hada) After type figures

Fig 15—*Fissurina lagenoides* (Williamson) After Williamson

Fig 16a b—*Fissurina oblonga* (Seguenza) Genotype of *Trigonulina* After type figures

Plate VII

Fig 1a c—*Fissurina cymbula* (Heron Allen and Earland) After type figures

Fig 2—*Fissurina testa* (Wiesner) After Earland 1934

Fig 3—*Fissurina staphyllearia* (Brady non Schwager) Section through specimen showing transition to *Parafissurina* Original Recent Kerguelen 20 30 metres

Fig 4a b—*Parafissurina mauricensis* (Howe and Wallace) After type figures

Fig 5a b—*Fissurina acutissima* (Fornasini) Genotype of *Ellipsolagena* After Fornasini 1890

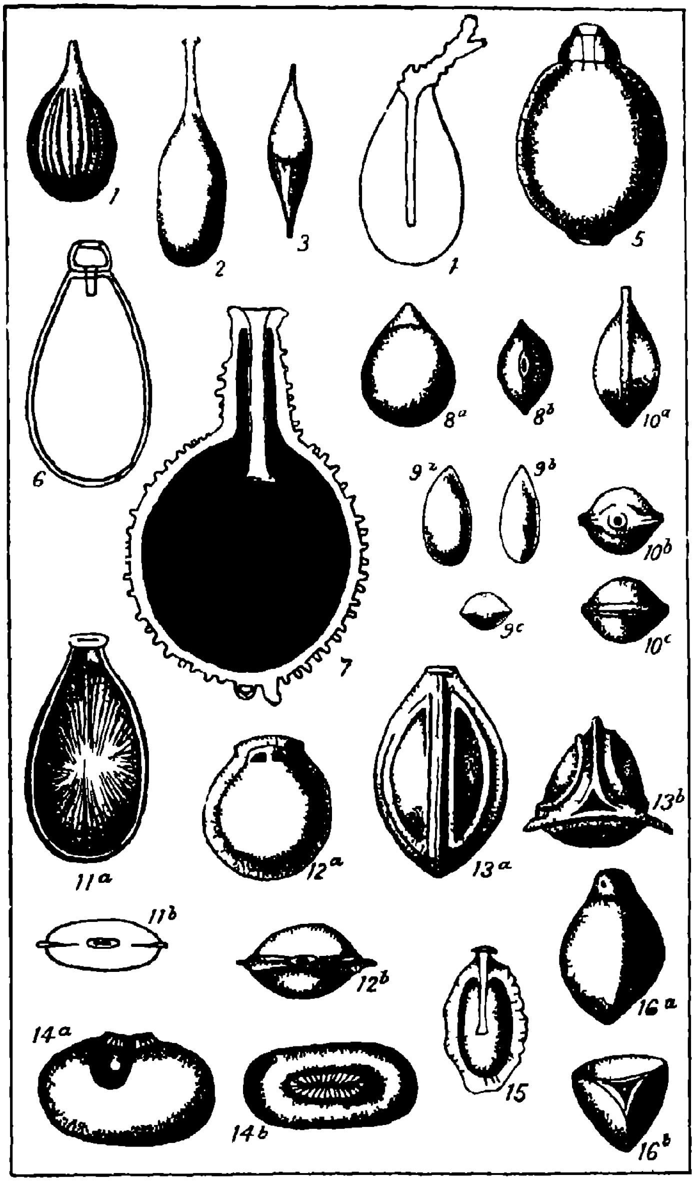
Fig 6a c—*Parafissurina schlichti* (A Silvestri) After type figures

Fig 7a c—*Parafissurina inaequilateralis* (J Wright) After type figures

Fig 8a c—*Parafissurina biccnica* (A Silvestri) After type figures

Fig 9a b—*Parafissurina millettii* (Chaster) After type figures

Fig 10a c 11—*Parafissurina* [illegible] (Millett) After type figures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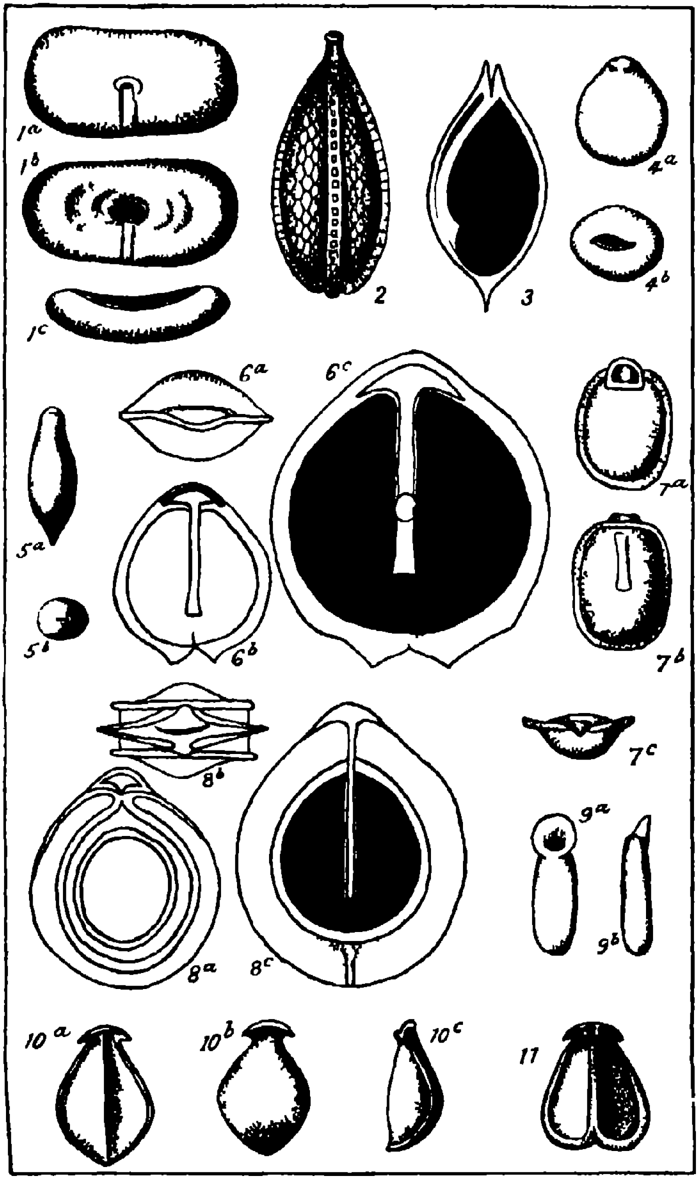
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[Proc Roy Soc Victoria, 58 (N S) Pts I–II, 1947]

Art XI—*A 200 K V Neutron Generator*

By L H MARTIN, R D HILL & J DARBY
(Physics Department University of Melbourne)

[Read 13th December 1945]

Abstract.

A brief account is given of a 200 K V Neutron Generator which can be readily constructed from materials available in an Australian laboratory The ion source is a deuterium glow discharge of the Oliphant type The equivalent activity of the generator is approximately 3 curies Rn – Be

Introduction

The simplest neutron source consists of a sealed tube containing beryllium powder mixed with radon Historically this was the first type of neutron source used

Although intense sources can be obtained by this method they suffer from the defects of decay with a half life of 3 8 days (the half life of Rn) and of an intense gamma ray background from the radon decay products

Artificial sources of neutrons have been developed using nuclear disintegrations in which neutrons are one of the products These sources have the advantage of being constantly available and beams of neutrons can be obtained with intensities far exceeding those available from natural radioactive sources

The practicability of obtaining intense neutron sources from low voltage acceleration apparatus (as distinct from the cyclotron and the high voltage van de Graaff apparatus) was demonstrated by Oliphant and Rutherford (1)

Neutrons were obtained from the D–D reaction in which accelerated deuterons disintegrate deuterium to produce helium of mass 3 and neutrons

i e $\quad {}_1H^2 + {}_1H = {}_2He^3 + n$

The efficiency of this reaction is comparatively high at low bombarding energies and the neutrons have approximately homogeneous energies in the region of 2 2 million electron volts

The yield of neutrons in the above reaction is a function of the energy of the bombarding ions and their number In high voltage generators such as the Van de Graaff machine the ion current is quite small usually of the order of 10 micro amperes In low voltage generators such as that described in this paper the use of large ion currents offsets the low energy of the ions To this end special attention has been directed to the design of the ion source and several different sources have been described Some of the more recent developments in neutron generator design are referred to in references (2) (3) (4) (5)

Acceleration Tube

Originally it was intended that 200 K V should be applied across a single gap as in the Philips neutron generator but it was found that continuous operation could not be attained above about 150 K V The failure to withstand the full potential was associated we believe with secondary electron emission and attempts to limit this by the development of a well focussed ion beam and by its careful alignment were not completely successful Accordingly the accelerating tube was divided into two sections, each built to withstand 100 K V and reliable operation at the full potential resulted immediately Stable functioning of the tube at full potential was effected also by using very high resistances (c. 10 megohm) in the leads to the tube electrodes. The purpose of these resistances is no doubt to limit the growth of a discharge which might be initiated by a small burst of gas in the tube.

The potential of the target is determined partly by the purpose for which the generator is required. If the neutron detecting apparatus can be taken to a safe electrical distance from the generator, and if the source is of sufficient intensity, the target may be worked at high (negative) potentials. On the other hand, if the disintegration products are to be observed close to the target, or if the most intense source is required, it may be essential to earth the target.

In our generator we have favoured the simpler arrangement of an earthed source and high potential target. This has the constructional advantages that the power supply and liquid cooling for the source do not require high potential insulation or motor generators operating at high potentials. This arrangement also has the advantage that the accelerating tube can be built upwards towards the high potential electrode and in our generator the target was arranged to be at a convenient height for counter and cloud chamber experiments.

The construction of the accelerating tube may be seen from Fig. 1. The outer envelope is formed by two glass cylinders which are joined together by a steel ring R, the joint being made vacuum tight by Apiezon Q sealing compound. The ring R also holds the central electrode system and is connected to the 100 K.V. terminal of the high potential supply. The first gap E is basically a plane electrode system. This form, after extensive

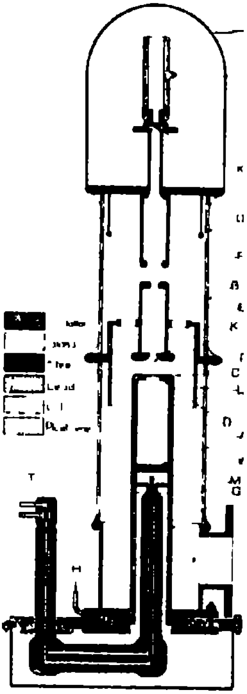

FIG. 1.—Neutron Generator.

tests, has proved the most satisfactory as far as stability against breakdown is concerned It has been found that breakdown is due primarily to electrons which are dislodged at the upper electrode by the periphery of the ion beam The electrode system shown in Fig 1 with the slightly curved upper electrode has the property of directing these electrons back into the region of the canal K and thus prevents them producing ionization in the main body of the discharge tube

It might be imagined that this electron emission could be reduced by increasing the aperture of the upper electrode in this gap There is a limit however to the size of this aperture since the electrostatic field is strongly defocussing for positive ions in this region

As a result of electrolytic tank experiments we tried cup shaped lower electrodes in this gap Although a cup electrode was designed with excellent focussing properties it was inferior to the plane electrode system in regard to breakdown The electric field while satisfactory for focussing positive ions allowed electrons from the upper electrode to escape into the tube

A lead shield L about 3 mm thick surrounds the first gap and reduces to a tolerable dosage the 100 K V X rays produced by electrons emitted at the upper electrode This shield also protects the middle glass metal joint from direct bombardment by ions scattered from the ion beam A similar shield O is provided for the upper glass metal joint The middle shield also effectively limits the range of secondary electrons

In the second acceleration gap I the upper electrode has an aperture of greater diameter than the lower electrode The defocussing effect of this system is less serious than it would be in the first gap since the ions are already moving with a high speed

The target X consists of a very thin layer of heavy paraffin wax melted on the underside of a ground copper plate It is cooled by a mixture of dry ice in alcohol placed in a dewar vessel V on the upper side of the copper plate The cooling mixture needs to be renewed about every half hour The whole target assembly is enclosed in a rounded metal shield N

The height of the target above the floor of the room is approximately 3 ft 6 in This is a most convenient height for manipulating specimens and counter equipment around the target and is particularly suited to experiments with the expansion chamber where neutrons are required to traverse the chamber horizontally

HIGH POTENTIAL SUPPLY

The rectifying circuit for the 200 K V generator is shown in Fig 2 Although the circuit is more complicated than is required merely to supply a potential of 200 K V it was chosen because it provides a mid point of potential The complication arises from the fact that the tank of the high tension transformer T_2 must be insulated from earth for 100 K V In the case of a two stage accelerating tube such as that described above the ion currents in each section are of different orders of magnitude and it is preferable to supply each section directly from a separate condenser rather than from a potential divider

The high potential supply was constructed from an old Greinacher ± 100 K V X ray plant In order to provide the transformer T_2 with the 100 K V insulation a second transformer T_1 was used to excite it Transformer T_1 was a discarded high tension transformer which was rewound with a 1/1 secondary winding and the insulation improved to withstand

100 K V The H T transformer T_2 was stood on 100 K V insulators and excited by the secondary of T_1 The filament transformer for the rectifier V_1 was also excited in the same way by a rebuilt 1/1 transformer insulated for 100 K V

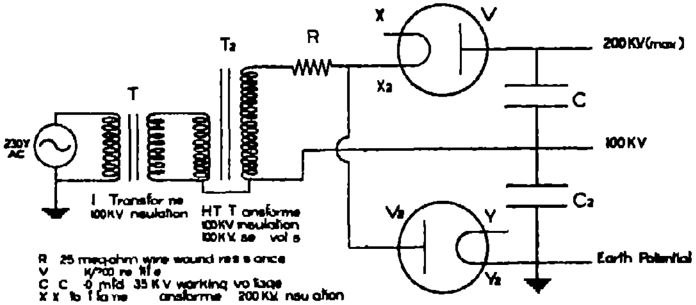

Fig 2—200 K V Supply Circuit

A stabilizing water load was placed directly across the output terminals of the supply The load was constructed from two coils of 3 mm diameter (inner) glass tubing each coil of about 25 feet length and with ordinary tap water flowing continuously it had a resistance of about 200 megohm

The ion currents flowing through the accelerating tube were measured by electrostatic voltmeters shunted with high resistances since it was found that ordinary moving coil meters were too liable to damage when a sudden breakdown occurred in the tube

All components of the high tension supply as well as the ion source supply were contained in a floor space of about 12 feet square and in a room 12 feet high The distance allowed between high voltage components and from surrounding objects was approximately 1½ inches per 10 K V

ION SOURCE

Two types of ion source have been developed for use with neutron generators namely the glow discharge source and the low voltage arc source The relative merits of these sources have been discussed by Craggs(2) Although it is likely that the low voltage arc source can provide an ion yield which exceeds that obtainable from the glow discharge source there is little doubt that the latter is simpler to operate and maintain than the low voltage arc and it was this feature that led us to employ the glow discharge source

The construction of the ion source is shown in the main drawing of Fig 1 It consists of two closed concentric cylinders A and C the former being maintained at a positive potential between 20 and 35 K V and the latter at earth potential The insulation of the anode A is provided by the glass cylinder G which was constructed in the following manner Two metal to glass seals were cut from a discarded Philips 200 K V Metalix X ray tube and the glass sections were then joined together in a glass lathe The seals have proved to be mechanically robust but must be protected from the gas discharge by a copper sleeve at M The device of placing the insulation for the anode A within the cylinder C has conserved a considerable amount of length in the generator Further length has also been conserved by providing the lead from terminal T to the anode A with oil and solid insulation In this way 35 K V to the anode can be handled to within 2 or 3 inches from the base on which the generator is mounted

In order that localized discharges will not build up between the walls of the cylinders A and C it is necessary to maintain the cylinders concentric with a separation of about 3 mm. The discharge is only strongly maintained between the anode block A and the cathode hole K. The diaphragm D suggested by Craggs has been used as an electrostatic lens to concentrate the discharge on the canal K. The anode runs hot under the intense electron bombardment from the discharge and solder seals are kept cool by a constant flow of water W behind the anode block. The supply of water comes from the mains through a coil of glass tubing to the inlet and outlet tubes on the terminal I. The water resistance has a value of about 60 megohms. The gas for the discharge is fed in through tube H and flows upwards between the concentric cylinders. Gas pressure in the discharge is approximately 0.1 mm Hg.

PREPARATION OF DEUTERIUM

Deuterium is prepared in the apparatus shown in Fig. 3 by the electrolysis of 99.6% heavy water. The volumes of the flasks and connecting tubes of the apparatus on the deuterium and oxygen side respectively are constructed as accurately as possible in the ratio 2 : 1. The electrolyte is prepared by dissolving 0.8 gm. of sodium peroxide in 20 c.c. of heavy water and driving off all the oxygen liberated by gentle heating under reduced pressure. After evacuating the apparatus through either tap A or B the electrolyte is introduced through the side tube C which is then sealed. In order to prevent excessive bubbling at the start when the gas pressure is low the current should be limited to about 50 mA. At higher pressures however higher currents can be employed. A current of about 0.5 amp. is normally used and the heat which is generated is dissipated in a bath of ice water. Because of the 2 : 1 ratio mentioned above the pressure on each side builds up at approximately the same rate and when atmospheric pressure is reached the oxygen bubbles off through the mercury manometer, the deuterium being pumped off to the ion source through a needle valve D. The current can be adjusted so that for a particular consumption of deuterium the pressure in the generator remains constant. If the deuterium

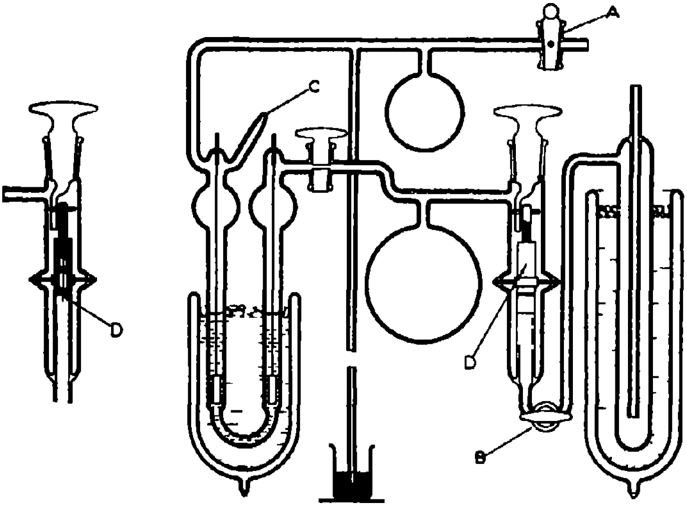

FIG. 3.—Deuterium Supply and Needle Valve

is generated too quickly the electrolyte is pushed below the level of the cathode and electrolysis automatically stops. The volume of the flask and connecting tubes on the deuterium side is about 425 cc. and it takes three hours to fill this at atmospheric pressure.

ION SOURCE CHARACTERISTICS.

Some typical characteristics of the ion source are shown in Table I, from which it appears that the ion yield increases with increasing potential on the discharge and is a maximum for an optimum gas pressure in the discharge tube.

TABLE I—DISCHARGE TUBE CHARACTERISTICS

Discharge Potential (K V)	Discharge Current (m A)	Ion Current (μ A)	Pirani Reading Divisions.
16	6	50	0·8
20	11·5	100	(approx ·1 mm Hg)
25	18·5	140	,,
30	21	160	,,
16	2	60	0·95
20	8	80	(slightly < ·1 mm Hg)
25	14	130	,,
30	20	170	,,
16	14	70	0·6
20	19	80	(slightly > ·1 mm Hg)
25	21	100	,,
30	24·5	120	,,

Some exploratory work has been done on finding the best size of the canal K. It has been found that the ion current issuing from the canal into the accelerating tube increases with increasing size of hole. For instance, the data of Table I. were obtained with a canal 1 mm. in diameter and 4 mm long; whereas with a hole 1·5 mm. diameter and 6 mm. long the yield at 30 K V and the optimum pressure was 230μA The geometrical divergence of the canal is the same in both cases The maximum canal diameter is, of course, determined by the relationship of the pressures in the discharge and accelerating tubes to the speed of the pumping system. For example, with a canal 2 mm. wide and 3 mm. long it was very difficult to control the discharge pressure at the optimum value, and the pressure in the accelerating tube was also too great to withstand 200 K.V. continuously.

Up to the present we have had no opportunity of testing the effect of the size of the hole in the diaphragm D on the ion yield. The measurements above have been obtained with a 1.3 mm. diameter hole spaced 3 to 4 mm. from the cathode, as recommended by Craggs.

PUMPING SYSTEM.

As has already been mentioned, the ultimate yield of the generator is intimately connected with the size of the canal and therefore with the amount of gas which issues from the canal Thus the pumping speed should be as large as possible. Further, in order that the full potential can be applied to the accelerating tube the mean free paths of ions and electrons in the gas of the tube must be long compared with the dimensions of the tube.

For a canal of 1mm. diameter and 4 mm. length the flow of hydrogen at a pressure of 10^{-1} mm. Hg. is approximately 90 litres per sec. The speed of pumping required at the first acceleration gap must therefore be of the order 100 litres per sec. at a pressure of from 10^{-4} to 10^{-5} mm. Hg. At these pressures the mean free path of a hydrogen molecule is from 1·3 to 13 metres.

We have used an oil diffusion pump having a speed of 300 to 500 litres per sec at the pressures 10^{-4} to 10^{-5} mm Hg to exhaust the accelerating tube Some trouble was experienced initially by having the pump too close to the accelerating tube as oil vapour entered the tube and the ionized products of the oil led to gaseous breakdown A length of water cooled wide diameter pipe with three right angle bends was then added to condense the oil before it entered the chamber With this connection the pumping speed was somewhat reduced but it remained in excess of 100 litres per sec

The oil diffusion pump was backed by a booster which could operate at a pressure of as high as 10^{-1} mm Hg and this in turn by a Megavac

NEUTRON YIELD

Typical measurements of the generator characteristics are shown in Table II

TABLE II—ACCELERATING TUBE CHARACTERISTICS

First Gap Current (μA)	Second Gap Current (μA)	Accelerating Potential (kV)
800	400	160
8[illegible]0	430	180
750	500	200

It will be noticed that the ratio of the target current to the current in the first gap increases with potential due no doubt to improved focussing as the speed of the particles increases The current to the target is seventy per cent of the ion current in the first gap indicating that the focussing of the ion beam is very satisfactory

The intensity appears to be comparable with that obtained by other workers At 200 KV the yield per 100 micro amps is approximately 600 millicuries

Under best working conditions our neutron generator is equivalent to 3 curies of Rn Be

Acknowledgments

The construction of the neutron generator is preliminary to the study of the interaction of neutrons and the deuterium nucleus This research is being carried out with funds made available by the Commonwealth Council for Scientific and Industrial Research

The gas generator referred to under the section on Preparation of Deuterium was developed by Mr D Keam of this laboratory

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[Proc. Roy. Soc. Victoria, 58 (N.S.), Pts. I.-II., 1947.]

Art. XII.—*The Thermal Conductivity of Carbon Dioxide between 78·50°C. and 100°C.*

By W. G. KANNULUIK, D.Sc., F.Inst.P., and P. G. LAW, M.Sc., A.Inst.P.

(Physics Department, University of Melbourne.)

[Read 13th December, 1945.]

According to the kinetic theory, the thermal conductivity of a gas should increase with the temperature. Although this prediction is generally confirmed by experiment, it is impossible to deduce from the existing experimental data any more specific conclusions. According to Loeb (Kinetic Theory of Gases, p. 251) "the results of the many experiments are none the less quite discordant and little can be deduced from them." On the other hand, the absolute values at 0°C. of the conductivities of some of the commoner gases are known with reasonable accuracy, and so it can be concluded that experimental procedures which lead to tolerably accurate values of the conductivity at 0°C are either inapplicable or unsuited to investigations carried out at other temperatures In the present paper an account will be given of some preliminary experiments undertaken to investigate the temperature variation of the conductivity of carbon dioxide gas. The method used is one that was developed twelve years ago, and was applied successfully to determine the conductivity of a number of gases at 0°C.(1). In those experiments a hot wire method was used in which the wire was relatively short and thick, instead of long and fine as in the older traditional forms of the hot wire method It would seem that the short thick wire offers greater prospects of success in a rather difficult field of investigation.

A short account of the two types of hot wire experiment will first be given. In all hot wire experiments a metal wire, which is heated by passing an electric current through it, is mounted axially in a glass or metal tube which contains the gas under investigation and which is immersed in a constant temperature bath The wire serves both as a resistance thermometer and as a heater of the gas in the tube. The average rise in temperature of the wire on passing a given current through it will depend on the conductivity of the gas surrounding the wire. The hot wire method depends on this fact, but carries with it the obligation of completely eliminating convection currents in the gas This problem was studied experimentally by Sophus Weber(2) and it is now possible to design and set up an apparatus in such a way that convection currents are completely absent. Three conditions which must be satisfied are (1) that the tube be mounted vertically, (2) that it is not too wide, and (3) that the temperature difference between the wire and the tube be kept small.

A difficulty which is met with to a greater or less extent in all hot wire experiments has its origin in the existence of a discontinuity of temperature at any solid-gas interface. The steeper the temperature gradient near the surface, the greater the temperature discontinuity or drop. The prevalent use of fine wires greatly aggravates the difficulty, the temperature gradient at the surface being much steeper for thin than for thick wires. The magnitude of the temperature drop increases with the mean free path of the molecules, i.e., with decreasing pressure of the gas. By making use of this fact it is possible to correct a set of values of the conductivity obtained at different pressures for the effect of the temperature drop.

The different kinds of hot wire apparatus being always symmetrically constructed, the distribution of the temperature along the wire is also symmetrical with respect to the two ends of the wire When the wire is sufficiently long and fine the graph of the temperature along the wire is shaped very like a top hat i e, there is a central portion of the wire along which the temperature is constant The length of this portion is relatively greater the longer the wire is and the smaller its diameter As there is no temperature gradient anywhere in this part of the wire all the Joule heat developed in it by the electric current must be carried away laterally from the surface of the wire by conduction through the gas and by radiation (assuming of course convection is absent) If the wire is uniform and has a truly circular cross section and if it be mounted along the axis of a truly cylindrical tube the flow of heat by conduction through the gas from the portion of wire at constant temperature is radial and takes place between concentric cylindrical surfaces defined by the wire surface and the inner surface of the tube If this particular portion of the wire can be isolated so that the measurements are made with respect to it and not the whole wire the theory of the experiment takes on a very simple character

The isolation can be effected in either of two ways In one of these due to Schleiermacher (1888)$^{(3)}$ the central portion is tapped by introducing two potential leads of very fine wire through the wall of the tube and attaching them to the wire at appropriate points In the other devised by Goldschmidt (1911)$^{(4)}$ two tubes are employed which are identical in all respects except that one is short and the other long The wire in the shorter tube plays a similar role to that of the compensating leads of the platinum thermometer The difference in the electrical resistance of the long and short tube will give the resistance of the central portion of the wire from which the flow of heat is radial

Let h be called the external conductivity defined as the loss of heat per second from unit area of the wire surface per degree difference of temperature between the wire and the tube Then if l be the length of the central portion and b the radius of the wire the rate at which heat is lost from the surface is

$$2\pi blh\ (t_1 - t_2)$$

where t is the temperature of the wire obtained indirectly from resistance measurements and t_2 is that of the tube The rate at which Joule heat is developed in the part of the wire under consideration is RI^2/J where R ohm is its resistance when the current is I ampere Since no heat is conducted along the wire it follows that

$$2\pi blh\ (t_1 - t_2) = RI^2/J \qquad (1)$$

where J = 4 18 joule/cal

All the quantities in this equation are either known or can be measured except h which can therefore be determined If the loss of heat from the wire by radiation is inappreciable compared with the loss by conduction the thermal conductivity k of the gas can be obtained by multiplying h by a certain form factor the value of which is determined by the fact that the flow of heat is radial and takes place between concentric cylindrical surfaces The appropriate form factor can be shown to be $b \log_e a/b$, a being the inner radius of the tube and b the radius of the wire Accordingly we write

$$k = h\, b \log_e a/b \qquad (2)$$

The type of hot wire experiment just described has a number of unfavourable features Whichever of the two methods is used for isolating the constant temperature part of the wire, an inconveniently long apparatus results For this reason such an apparatus is unsuitable when measurements of the conductivity over a range of temperature are required The diameters of the hot wires used are quite small (usually a few thousandths of an inch only) and cannot be determined as accurately as those of thick wires In some investigations merely an average diameter of the wire is obtained by weighing in air and in water a known long length of the wire used As the temperature gradient at the surface of such fine wires is very great, the wire should be uniform and accurately circular in section These are requirements which can be verified only by contact measurements

The above type of hot wire experiment was devised before modern high vacuum technique was developed The use of the short thick hot wire is made to depend upon the fact that, when a sufficiently high vacuum is produced in the tube all the Joule heat generated by the electric current is conducted out of the ends of the wire and none is lost laterally except a very small amount by radiation which can be allowed for by calculation Thus an experiment performed when the tube is highly evacuated leads to a determination of the thermal conductivity of the wire itself It is clear that in this kind of hot wire experiment when the tube contains a gas some heat is conducted along the wire and some is also lost laterally The theory is necessarily less simple but the gains on the experimental side are so great as to more than compensate for its use

The following simplified account of the theory is sufficient to illustrate the principles of the method For calculating the conductivity it is however necessary to use the more accurate theory given in the Appendix to this paper

For a short thick wire of radius b mounted axially in a tube maintained (say) at 0°C the distribution of temperature along the wire can be shown to be very nearly parabolic Accordingly if the centre of the wire (length 2l) be taken as origin the temperature at any point on it distant x from the centre will be given by

$$t = c\,(l^2 - x^2) \qquad (3)$$

c being a constant (see fig 1)

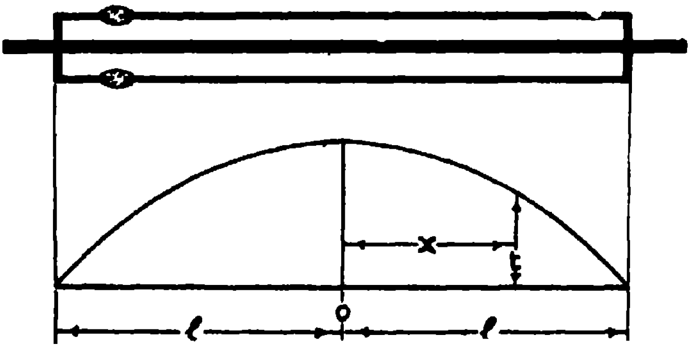

FIG 1

Clearly the temperature has a maximum value of cl^2 at the middle and it is zero at both ends.

The mean temperature of the wire can easily be shown to be. $\bar{t} = 2cl^2/3$.

$$\left(\bar{t} = \frac{1}{2l}\int_{-l}^{+l} c(l^2 - x^2)\,dx = 2cl^2/3\right)$$

The temperature gradient at any point in the wire is, by (3):

$$\frac{dt}{dx} = -2cx$$

At either end the gradient is therefore:

$$\left(\frac{dt}{dx}\right)_{x=+l} = -2cl = -\frac{3t}{l}$$

The rate at which heat is conducted out of the wire at the two ends is:

$$2\left(-\lambda A\left(\frac{dt}{dx}\right)_{x=+l}\right) = \frac{6\lambda\pi b^2\bar{t}}{l}$$

λ being the thermal conductivity of the wire, and $A = \pi b^2$ its cross-section

The rate at which heat is lost from the surface of the wire is:

$$2\pi b \,.\, 2l \,.\, \bar{t} \,.\, h = 4\pi b\, l\, h\, \bar{t}$$

where h is the external conductivity.

The rate at which heat is generated in the wire by the electric current is $\bar{R}I^2/J$ where $\bar{R}$ is the resistance of the wire when the current is I ampere The sum of the heat lost per second by internal conduction and by external conduction must equal the joule heat produced per second by the current. Accordingly we have:

$$\frac{6\lambda\pi b^2}{l}\bar{t} + 4\pi l\, b\, h\,\bar{t} = \frac{\bar{R}I^2}{J} \qquad (4)$$

If α be the temperature coefficient of the resistance, then for a small rise of temperature:

$$\bar{R} = R_0(1 + \alpha\bar{t})$$

where R_0 is the resistance of the wire at 0°C Solving for $\bar{t}$ we obtain:

$$\bar{t} = \frac{\bar{R} - R_0}{R_0\alpha}$$

and substitution of this value of $\bar{t}$ in (4) gives:

$$\frac{6\lambda\pi b^2(\bar{R} - R_0)}{R_0\alpha l} + \frac{4\pi bhl(\bar{R} - R_0)}{R_0\alpha} = \frac{\bar{R}I^2}{J}$$

or

$$\frac{h}{b} = \frac{R_0\bar{R}I^2\alpha}{4(\bar{R} - R_0)\pi b^2 Jl} - \frac{3\lambda}{2l^2} \qquad (5)$$

For the special case in which there is a high vacuum in the tube we may put h = 0 in (5) and so obtain Knudsen's formula:

$$\lambda = \frac{1}{6} \cdot \frac{\bar{R}\, R_0\, I^2\, \alpha\, l}{J\, \pi\, b^2 (\bar{R} - R_0)} \qquad (6)$$

Knudsen proved that it was possible to measure the thermal conductivity of a metal accurately by means of (6), using a platinum wire a couple of centimetres in length and a few tenths of a millimetre in diameter. The conductivity of the wire having been determined by (6), the value of λ is next introduced into (5), which equation may then be solved for h and the conductivity of the gas is obtained, as in the other method, through (2). The form factor b $\log_e$ a/b is an approximation as the flow of heat by conduction through the gas is not strictly radial. The error introduced into k by its use can be proved to be less than 1 per cent. It follows that the accuracy with which the conductivity of a gas can be obtained by this method depends upon the accuracy with which the conductivity of the wire is obtained. It will be noticed that if the current is kept constant the only quantity which has different values in (5) and (6) is $(\bar{R} - R_0)$, and that for a given current $(\bar{R} - R_0)$ necessarily has its maximum value in (6), i.e., under high vacuum conditions, and here optimum accuracy in its measurement is most desirable.

The method described has, in the earlier work⁽¹⁾, been submitted to searching tests, by varying all the factors upon which the conductivity of a gas depends. Wires and tubes of different materials and dimensions have been tried. Both platinum and copper wires were employed, and although the thermal conductivity of copper is six times that of platinum, practically identical values of the conductivity of air, as also of hydrogen gas, were obtained.

Description of the Apparatus

In order to investigate the conductivity at fixed temperatures other than the ice point, a small and compact conductivity apparatus is essential if accurate temperature control is to be achieved One form of the apparatus used in the earlier work at the ice point was judged suitable for measurements of the conductivity at the steam point (100°C.), the ice point (0°C.), the carbon-dioxide point (—78·50°C.), and the oxygen point (—183°C.). This apparatus consisted of a platinum wire 1·5 mm. in diameter mounted in a stainless steel tube 10 cm. long, and having an internal diameter of 12 mm Some preliminary tests made with this apparatus (which had been out of use for twelve years) indicated that some deterioration in the soft solder used in fixing the wire in the tube had occurred. It was therefore decided to dismantle the apparatus and re-assemble it using silver solder wherever soldering was necessary. The inner surface of the tube was re-lapped and a new copper-glass seal was made. The platinum wire was re-drawn using diamond dies and then carefully annealed at 950° in a muffle furnace. A recently-calibrated set of slip gauges was used in conjunction with micrometer screw gauges and a pair of internal jaws to determine the dimensions of the tube and wire, and the tube was then re-assembled. Fig 2 is a sketch of the completed apparatus. The wire is insulated electrically from the steel tube by means of a double glass copper join G in the lower copper end-cap C. The tube is closed at either end by a thin copper end-cap, about 1 mm. thick, through the centre of which the wire is soldered. The side tube T is sealed to a wider glass tube leading off to a vacuum pump, a simple U-tube mercury manometer, a discharge tube, and a tap through which gas may be introduced. The current and potential leads immediately above the tube were wrapped in cotton wool to protect them from draughts, which, particularly in steam point determinations, had produced fluctuations in current and potential readings.

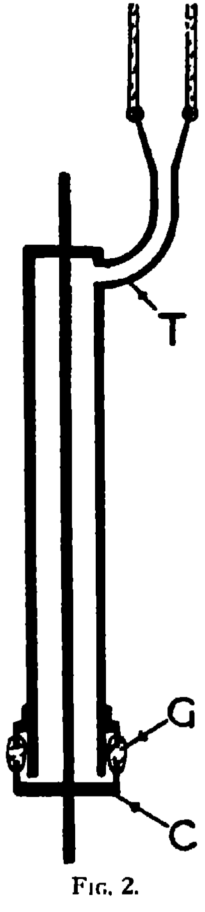

FIG. 2.

In order to measure the thermal conductivity of a gas, the apparatus is pumped out through one tap and the pure gas is then introduced through another until its pressure in the apparatus is approximately atmospheric pressure. The gas is later pumped off a little at a time in order to enable readings at various pressures to be taken.

When a determination of the thermal conductivity λ of the wire is to be made, the mercury manometer is removed and a tube containing activated charcoal is substituted for it. The high vacuum required is obtained in the usual way by immersing the charcoal tube in liquid air after degassing the charcoal

DIMENSIONS OF TUBE AND WIRE AT 0°C

Mean distance between the internal faces of the copper end-caps (i e, effective length of the platinum wire) = 103·87 mm. ± ·05 mm.

Mean internal diameter of steel tube
= 12·814 mm ± ·005 mm.

Mean diameter of platinum wire
= 1·438 mm ± ·003 mm.

MEASUREMENT OF ELECTRICAL QUANTITIES.

Apart from the dimensions of the wire and the tube, the other quantities required are electrical ones, viz.: R_0, the resistance of the wire at the temperatures of the constant temperature bath in which the apparatus is immersed; α, the temperature coefficient of the resistance at that temperature; $\overline{R}$, the measured resistance of the wire when it carries a steady current of I amperes.

Of these, R_0 and α are electrical constants which are both obtained indirectly from measurements of $\overline{R}$.

The quantities $\overline{R}$ and I are obtained directly by comparing the drop of potential across the wire with the drop across a standard ·01 ohm resistance by Tinsley. A five-dial Diesselhorst low-resistance potentiometer made by Wolff, is used to measure the potential drops. Although the circuit used is a very simple one, great care must be taken in setting it up in order to obtain electrical stability. The work is carried out in a room in which the temperature remains approximately constant near 20°C., the resistances of the coils of the potentiometer being correct at this temperature

It is not convenient to measure R_0 directly. Instead, a series of values of $\bar{R}$ for different values of I is obtained (whether the tube be evacuated or left filled with a gas is immaterial so long as the conditions inside the tube remain the same during these readings). Corresponding values of $1/\bar{R}$ and I^2 are then plotted upon a large sheet of graph paper. The points so obtained lie very accurately upon a straight line and the line is extrapolated to give $1/R_0$ corresponding to $I = 0$. The value of R_0 actually adopted is obtained by calculation, rather than from the drawn graph, using Cauchy's method (for which see Champion and Davy, Properties of Matter, p. 267).

To obtain α, the variation of the resistance of the platinum wire with the temperature is determined. For platinum it is sufficient to use the two-constant formula:

$$r = (1 + at + bt^2)$$

between — 78·50°C. and 100°C., where $r = R_t/R_0\,0°C$ or the ratio of the resistance at t°C. to the resistance at the ice-point, and a and b are numerical constants. Measurements of the resistance were made at the ice-point, the steam point, and the carbon dioxide point (—78·50°C).

The temperature coefficient α at any required temperature t is then given by:

$$= (a + 2bt) \ : \ Rt/R_0°C$$

The following figures were obtained·

—	−78·50°C	0°C	100°C
Resistance (R_t)	·00437078	($R_0$0°C) ·00639501	·00889662
α ..	·0059299	·0039705	·0027709
	a = ·0039706	*b* = −·000000575	

The above values of *a* and *b* lead to the following value of the δ coefficient used in platinum thermometry

$$\delta = -10^4\, b/(a + 100b) = 1·49$$

NOTE ON THE ATTAINMENT OF THE CO_2 POINT.

In order to make measurements at the CO_2 point (—78·50°C.) it was required that the tube be kept at this constant temperature for at least two hours. The tube is nearly 4½ inches long, and is connected by current and potential leads to the rest of the apparatus. When the tube is placed in the CO_2 bath, heat tends to be conducted to the tube from outside along these leads. Moreover, heat is generated in the wire in the tube at the rate of approximately ·07 watt, and this must be dissipated by the bath. The conditions are thus more exacting than is generally the case for ordinary thermometric work.

A separate investigation was required to determine how a dry-ice bath might be used to give satisfactory results. An examination of the literature showed that other workers who had attempted to use this fixed point for thermometric work had experienced difficulty and apart from a paper by Zeleny and Zeleny(8), little information of any assistance to us was discovered.

The conduction of heat to the tube along the leads was overcome by replacing the lead wires in the vicinity of the tube by thin wide strips of copper which ran parallel with the tube and traversed 5½ inches of the bath before being soldered to the tube. Good thermal contact between the strips or tube and the bath was obtained by using a wet slush of dry ice chips and ethyl alcohol.

The use of a Dewar flask as a receptacle for the dry ice mixture is not recommended. It was not until its use was abandoned that success in the handling of the bath was obtained.

The tube was placed centrally in a glass gas cylinder 12 inches tall and 2½ inches in diameter which stood on ½ inch of felt on a wooden stand. The sides of the cylinder were lagged with two layers (about 1½ inches uncompressed) of cotton wool which also extended about 2 inches above the top of the jar. A single layer of paper was then tied around the lagging. The dry ice was reduced to fine chips by means of an ice grinder and these chips were mixed with ethyl alcohol in an aluminium saucepan until a wet but not sloppy mixture was obtained. This was fed by spoon into the jar surrounding the tube. The mixture in the jar was then prodded with a long thin metal rod to ensure that it was well packed down and the jar was "topped up" with more wet ice. Finally some alcohol was cooled with dry ice and added to the jar until about ½ inch of free alcohol remained above the surface of the dry ice chips.

The tube was left for at least five minutes at the end of which time a *gentle* bubbling of gas through the surface alcohol could be observed. Thereafter no stirring or prodding was permitted although the original level and the ½ inch depth of free alcohol were maintained by adding chilled alcohol or wet dry ice as required.

It was found that such a mixture of dry ice and alcohol with free alcohol on top when lagged with sufficient cotton wool to reduce the evolution of gaseous carbon dioxide to a gentle steady rate would maintain the tube at the CO_2 point for a period of several hours and in general would behave as satisfactorily as an ice water bath for the 0°C point.

It was necessary to apply a correction to allow for the hydrostatic pressure of the alcohol at the point in the bath where the temperature was being measured. In this experiment the hydrostatic pressure at the centre of the tube was calculated and the temperature of the bath at this depth was taken as the mean temperature of the tube.

DETERMINATION OF λ

To determine λ the apparatus is evacuated and a high vacuum ($< 10^{-6}$ mm of mercury) is produced by means of charcoal and liquid air. The values of $\bar{R}$ corresponding to a series of different values of the current I are obtained and the conductivity λ' is calculated using formula (6) in the Appendix. (The platinum wire is not sufficiently short to use Knudsen's simpler formula (6) given in the elementary theory.)

RESULTS.

Temperature	$-78{\cdot}50°$C	0°C.	100°C.
λ cal. cm^{-1} sec^{-1} deg.$^{-1}$	·1603 ± ·0002	·1675 ± ·0002	·1690 ± ·00013

The value of λ at $-78{\cdot}50°$C was confirmed by several independent determinations.

DETERMINATION OF k.

The conductivity λ of the wire being known, the apparatus may then be immersed in a constant temperature bath and filled with the gas to be investigated. The current I is set to give a mean rise of temperature of the wire of 3–5 degrees. Corresponding values of $\overline{R}$ and I are then obtained at a series of different pressures of the gas.

The approximate conductivity k′ of the gas is found at each pressure of the gas by solving the equation (4) (or (5)) in the Appendix for h and then k′ is deduced by multiplying h by the form factor b $\log_e$ a/b.

As the flow of heat is not exactly radial (4) or (5) leads to approximate values k′ of the conductivity, but by making use of relations (9) and (8) of the exact theory the amount of the correction to k′ can be worked out. This proves to be quite small, being just under 1 % over a wide range of conductivities. It is sufficient to reduce the conductivity k′ as calculated from (4) (or (5)) by 1% to obtain the value k corrected for the departure from radial flow.

EFFECT OF TEMPERATURE DISCONTINUITY.

On account of the temperature discontinuity at the surface of the wire and at the inner surface of the tube, the space factor for radial flow should be replaced by:

$$h \left[\log_e a/b + \gamma \, (1/a + 1/b) \right] \qquad (6)$$

where γ is related to the temperature discontinuity Δ T by the equation of Poisson:

$$\Delta T = \gamma \frac{dT}{dn}.$$

Here dT/dn is the temperature gradient along the outward drawn normal and γ is a length quantity which varies inversely with the pressure.

It has been found that k at O°C is, in general, constant over a wide range of pressures (60–10 cm. of mercury) for the monatomic and diatomic gases investigated by the apparatus containing the thick platinum wire⁽¹⁾. From these results it is inferred that the effects of convection and of the temperature discontinuity are negligibly small for the range of pressures quoted.

(It should be noted that the effect of reducng the pressure of the gas on its apparent conductivity is to decrease this if convection is present, and also to decrease it on account of the temperature dscontinuity. Consequently, if it is found that k is strictly constant over a range of pressures there can be no convection present and the effect of the temperature discontinuity is likewise negligible.)

THE THERMAL CONDUCTIVITY OF CARBON DIOXIDE

The gas was prepared by heating pure sodium bicarbonate and dried by passing through calcium chloride and phosphorus pentoxide

The following results were obtained —

(*a*) At CO_2 Point Mean Temperature of Gas —76 4°C

Pressure (Cm of Hg)	Current (I amp)	R R, (Ohm)	k x 10^5 (7 4 ((Cal cm sec deg ¹)	k x 10^5 (78 50°C) (Cal cm sec deg⁻¹)
77 21	3 691'7	00010037	2 2 6	17
65 01	3 69070	100' 2	23	- 181
55 56	3 69046	10096	2 1 5	1(2
43 51	3 68985	10115	2 132	080
32 96	3 68963	10124	2 1 2	0
22 59	3 68903	10137	2 104	- 0.3
14 20	3 68864	10160	2 079	028
8 24	3 68827	10178	2 060	2 010
3 25	3 68819	10207	2 093	1 983
1 42	3 68766	102-6	2 018	1 969
0 23	3 68736	10237	1 996	1 947

In the last column the radial flow correction has been applied and the conductivity reduced to 78 5°C using a temperature coefficient of 007

(*b*) At Ice Point Mean Temperature of Gas 2 1 C

Pressure (Cm of Hg)	Current (I amp)	R − R, (Ohm)	k x 10^5 (2 1°C) (Cal cm ¹ sec ¹ deg⁻¹)	k x 10^5 (0°C) (Cal cm ¹ sec ¹ deg⁻¹)
67 94	341 29	00010398	3 644	3 5)
26 92	3406-7	1039	3 (18	3 544
9 63	340725	1040(	3 599	3 525
- 35	340596	10417	3 575	3 501
1 122	340499	10419	3 67	3 494
854	340387	10413	3 566	3 493
651	340315	10410	3 564	3 491
394	340238	10431	3 542	3 469
271	340166	10451	3 504	3 43

In the last column the radial flow correction has been applied and the conductivity reduced to 0°C using a temperature coefficient of 006

(*c*) At Steam Point Mean Temperature of Gas 102 0 C

Pressure (Cm of Hg)	Current (I amp)	R − R, (Ohm)	k x 10^5 (102°C) (Cal cm ¹ sec⁻¹ deg⁻¹)	k x 10^5 (100 C) (Cal cm ¹ sec⁻¹ deg⁻)
78 41	2 98103	00009051	5 705	5 604
39 18	2 98058	9150	5 588	' 489
21 50	2 98000	91 0	5 535	5 467
12 21	2 97949	9179	546	5 448
4 23	2 97884	9198	5 511	414
1 61	2 97829	9 45	5 435	5 330

In the last column the radial flow correction has been applied and the conductivity reduced to 100°C using a temperature coefficient of 004

Discussion of Results

These conductivity data for all three temperatures (on account of their gradual decrease with the pressure) are evidently affected by the existence of the temperature discontinuity effect To allow for this effect the usual procedure is followed of plotting the reciprocal of k against the reciprocal of the pressure p The plot of points so obtained is straight over a range of pressure in which convection is absent To obtain the value of k unaffected by the temperature discontinuity the straight portion of the graph is extrapolated to give the value of 1/k corresponding to 1/p = O. In this way the following values of the thermal conductivity of carbon dioxide are obtained:—

Temperature °C	−78·50°C	0°C	100°C.
$k \times 10^5$ cal cm^{-1} sec^{-1} deg^{-1}	1·07	3·50	5·46

There is also a second possibility that the observed variation of k with the pressure p is only in part the result of the temperature discontinuity. Ubbelohde$^{(7)}$ has suggested that as the pressure of the gas is reduced the participation of the vibrational energy of the carbon dioxide molecules in the transport of heat becomes less and less complete This also would result in a decrease in k with the pressure

Some recent measurements by us on monatomic argon gas show much less variation of k with p It seems not unlikely that part of the decrease of k with p is concerned with the decrease in the transport of heat by the vibrational energy of the carbon dioxide molecules

Appendix

THEORY OF THE METHOD

The following approximate theory in which the flow of heat from the wire through the ambient gas is assumed to be strictly radial leads to values of the thermal conductivity k′ which are in error by a little less than 1 %. This can be shown to be the case by comparing the values of k as obtained from the approximate theory and from the exact theory which follows later Accordingly, it is sufficient to use the approximate theory to work out the results and then to apply the small correction which allows for the departure from radial flow

APPROXIMATE THEORY.

Let a wire of length 2l and thermal conductivity λ be mounted axially in a tube which is maintained at some constant temperature whch may be taken as an arbitrary zero Let the annular space between the wire and the tube be filled with a gas of conductivity k.

If the flow of heat from the wire is strictly radial then we have:—

$$\pi b^2 \lambda \frac{d^2t}{dz^2} - 2\pi b h t + \frac{I^2 R_0(1+\alpha t)}{2lJ} = 0 \qquad (1)$$

where $R_0\ (1 + \alpha\ t)$ is the resistance of the wire at t°, R_0 is the resistance at the temperature of the bath in which the apparatus is immersed, and b is the radius of the wire. The first two terms of (1) multiplied by dz represent the net rate of inflow of heat into an element dz along the wire and over its surface, while the last term multiplied by dz is the rate at which heat is produced electrically in the element of length dz. If the following substitutions be made:—

$$\mu^2 = \frac{2h}{b\lambda}, \quad m = \frac{I^2R_0}{2\pi b^2 lJ\lambda}, \quad \beta^2 = \mu^2 - m\alpha \text{ and } v = t - \frac{m}{\beta^2}$$

(1) reduces to

$$\frac{d^2v}{dz^2} - \beta^2 v = 0$$

For $\beta^2 > 0$ the solution of this equation is:—

$$t - \frac{m}{\beta^2} = A \sinh \beta z + B \cosh \beta z$$

where A and B are arbitrary constants. If the origin of z be placed at the middle of the wire the boundary conditions are $t = 0$ at $z = \pm l$ whence, after evaluating A and B, we obtain:—

$$t = \frac{m}{\beta^2}\left(1 - \frac{\cosh \beta z}{\cosh \beta l}\right) \qquad (2)$$

giving the distribution of temperature along the wire

For a sufficiently short and thick wire the distribution of temperature is very nearly parabolic, as can be seen by substituting the first two terms of the expansions for cosh βz and cosh βl. The parabolic distribution was assumed in the elementary theory previously given

The mean temperature $\bar{t}$ along the wire is given by:—

$$\bar{t} = \frac{1}{2l}\int_{-l}^{+l} \frac{m}{\beta^2}\left(1 - \frac{\cosh \beta z}{\cosh \beta l}\right) dz$$

or

$$\bar{t} = \frac{m}{\beta^2}\left(1 - \frac{\tanh \beta l}{\beta l}\right) \qquad (3)$$

If $\bar{R}$ is the observed resistance of the wire at the mean temperature $\bar{t}$ then $\bar{R} = R_0(1 + \alpha\bar{t})$, giving

$$\bar{t} = \frac{\bar{R} - R_0}{R_0\,\alpha}.$$

(In actual experiments $\bar{t}$ is 3 or 4 degrees only.) Accordingly, on substituting for $\bar{t}$, (3) becomes:

$$\left(\frac{1}{\beta l}\right)^2\left(1 - \frac{\tanh \beta l}{\beta l}\right) = \frac{2\pi b^2\lambda J(\bar{R} - R_0)}{R_0^2 I^2 \alpha l} \qquad (4)$$

(4) may be written in the form:

$$\frac{c}{\bar{R} - R_0} = \frac{\beta^3 l^3}{\beta l - \tanh \beta l}$$

where

$$c = \frac{R_0^2 I^2 \alpha l}{2\pi b^2 J\lambda}$$

Expanding tanh βl as a power series we obtain :

$$\frac{c}{\bar{R}-R_0} = \frac{\beta^3 l^3}{\beta l - (\beta l - \frac{1}{3}\beta^3 l^3 + 2/15\ \beta^5 l^5 - 17/315\ \beta^7 l^7 + \ldots)}$$

$$= 3\left[(1 + 2/5\ \beta^2 l^2) - \frac{\beta^4 l^4}{525}\right] \text{ (nearly)}$$

For values of βl not greater than unity, the error introduced in the right-hand side of the last equation by neglecting the term $\beta^4 l^4/525$ is small, e.g. for $\beta l = 1$ it is 1 in 300. If this term be neglected, we obtain, after simplification:

$$\frac{2h}{b\lambda} = \frac{R.I^2 \alpha}{2\pi b^3 J l}\left[\frac{5R_0}{6(\bar{R}-R_0)} + 1\right] - \frac{5\lambda}{2l^2} \qquad (5)$$

If λ is known, (5) can be solved at once for h, and the conductivity k′ of the gas obtained by multiplying h by the 'form factor' for radial flow between concentric cylinders, i.e.:—

$$k' = h \cdot b \log_e a/b.$$

where a is the inner radius of the tube

The wires used in our experiments are not sufficiently short and thick for (5) to be applicable to the high conductivity gases, hydrogen, deuterium and helium It is therefore necessary to solve the more general equation (4) for h This is most conveniently done by tabulating the function —

$$f = \left(\frac{1}{\beta l}\right)^2 \left(1 - \frac{\tanh \beta l}{\beta l}\right)$$

for different values of βl

When the tube contains a high vacuum (pressure not greater than 10^{-6} mm. Hg) the only lateral loss of heat from the wire is a very small one due to radiation, as the loss due to molecular conduction in the residual gas as shown below is negligible If h_R be written for h in (5) this equation enables us to obtain the thermal conductivity λ of the wire since h_R may be obtained by calculation from radiation data It is, however, more convenient for purposes of calculation to transform (5) into the equivalent form :—

$$\lambda = \frac{1}{6}\frac{\bar{R}R_0 l^2}{\pi b^3 J(\bar{R}-R_0)}\frac{\alpha}{}\frac{1}{}\left(1 + \frac{1}{30}\frac{R_0 I^2}{\pi b^3}\frac{\alpha}{J}\frac{l}{\lambda}\right)\left(1 - \frac{4}{5}\frac{h_R l^2}{b\lambda}\right) \qquad (6)$$

This relation replaces the simpler relation (6) of Knudsen, given in the elementary theory The quantites in the last two brackets on the right hand side of (6) represent small corrections only. It is therefore sufficient to use the approximate value of λ given by Knudsen's simple formula in evaluating them The quantity h_R can be readily obtained The radiation per cm^2 per second from a metal surface is:—

$$S = \epsilon \sigma T^4$$

where σ is Stefan's constant, T the absolute temperature, and ϵ the emissive power of the metal surface. It follows that:—

$$h_R = 4\epsilon\sigma T^3$$

The value of ϵ for a given metal can be obtained from experimental curves representing ϵ as a function of the wavelength. (The curves given in Geiger-Scheel, Handbuch der Physik, Vol. 21, p 190, may be used.) The wavelength λ_{max} corresponding to a given temperature T can be obtained from Wien's Displacement Law:—

$$\lambda_{max} T = \cdot 288 \text{ cm deg}$$

The validity of (6) depends also on the heat transfer by molecular conduction in the high vacuum being negligible. It can be readily shown from a relation obtained by Knudsen (for which see Lorentz "Lectures on Theoretical Physics," vol. 1, p. 144) that the loss of heat per cm^2 per sec. from a wire at t°C to a coaxial surrounding cylinder at the temperature of 0°C which contains air at a pressure of p dyne cm^{-2} is --

$$W < 3 \times 10^{-6} p \cdot t$$

This gives to the part h_c of h due to molecular conduction a value --

$$h_c < 4 \times 10^{-7} \text{ cal cm}^{-2} \text{ sec.}^{-1} \text{ deg}^{-1}$$

when the pressure is 10^{-4} mm of mercury Even at this pressure the effect of ignoring molecular conduction in (6) results in an error in λ of less than 1 part in 1000

EXACT THEORY

In the exact theory, for which we are indebted to Professor T Cherry, the differential equation (1) must be replaced by the following differential equation holding at the surface of the wire -

$$\lambda \pi b^2 \frac{\partial^2 t}{\partial z^2} + 2 \pi b k \left.\frac{\partial t}{\partial r}\right|_{r=b} + \frac{I^2 \rho_0}{J} (1 + \alpha t) = 0 \quad (7)$$

where ρ_0 is the resistance of the wire per unit length As before, the first two terms multiplied by dz represent the net rate of inflow of heat into the element dz along the wire and over its surface, while the last term multiplied by dz is the rate of generation of heat in dz by the electric current.

The solution of (7) is —

$$t = \sum_n c_n \left[I_0 (nsr) / I_0 (nsa) - K_0 (nsr) / K_0 (nsa) \right] \cos nsz$$

where $s = \pi/2l$, (n being odd)

and $$\left.\frac{\partial t}{\partial r}\right|_{r=b} = \Sigma c_n ns \left[I_1 (nsb) / I_0 (nsa) - K_1 (nsb) / K_0 (nsa) \right] \cos nsz$$

$$= \Sigma c_n ns N_{1n} \cos nsz \text{ (say)},$$

and $$\left.\frac{\partial^2 t}{\partial z^2}\right|_{r=b} = - \Sigma c_n (ns)^2 \left[I_0 (nsb) / I_0 (nsa) - K_0 (nsb) / K_0 (nsa) \right] \cos nsz$$

$$= - \Sigma c_n (ns)^2 N_{0n} \cos nsz \text{ (say)},$$

and $t_{r=b} = \Sigma c_n N_{0n} \cos nsz$

Also, for $-l < z < +l$

$$I^2\rho_0/J = \left[4I^2\rho_0/J\pi\right]\left[\cos sz - \tfrac{1}{3}\cos 3sz + 1/5 \cos 5sz \ldots\ldots\right]$$

Hence, on substituting in (7) and equating coefficients of cos nsz we get:

$$c_n = \pm\left[2I^2R_0/nJ\pi l\right] \div \left[\lambda\pi b^2 (ns)^2 N_{0n} - 2\pi bk\,(ns)\,N_{1n} - I^2R_0\alpha N_{0n}/2Jl\right] \tag{8}$$

the sign being + for n = 1, 5, 9 ...., and — for n = 3, 7, 11 ....

The resistance of the whole wire from $z = -l$ to $z = +l$ is

$$\bar{R} = \int_{-l}^{+l} \rho_0 (1 + \alpha\, t)dz = 2\rho_0 l + \left[4\rho_0 l\, \alpha\,/\pi\right]\left[c_1 N_{01} - \tfrac{1}{3} c_3 N_{03} + \tfrac{1}{5} c_5 N_{05} - \ldots\right]$$

or, since $R_0 = 2\,\rho_0\, l$

$$\pi(\bar{R} - R_0)\,/\,2R_0\alpha = c_1 N_{01} - \tfrac{1}{3} c_3 N_{03} + \tfrac{1}{5} c_5 N_{05} \ldots. \tag{9}$$

where $N_{0n} = I_0\,(nsb)\,/\,I_0\,(nsa) - K_0\,(nsb)\,/\,K_0\,(nsa)$

The equations (8) and (9) together replace (4) of the approximate theory. It will be noticed that the thermal conductivity k of the gas occurs only in the co-efficients c_n defined by (8). The series on the right hand side of (9) converges very rapidly and the calculation of the first three terms allows k to be obtained by successive approximations. The expansions of the Bessel functions I_0, I_1 and K_0 are given in Whittaker and Watson, Modern Analysis, Chapter 17.

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10, 9 mm.; lengths of lower margin to base of immovable finger 15, 13, 11, 10.4, 9.5 mm.; maximum heights 10.5, 9.5, 9, 8.5, 6.7 mm.; minimum heights 8.5, 8.7, 7.7, 7.5, 5.7 mm. The upper edge is straight and curves gently downward near its proximal and distal ends. It forms a right angle with the straight proximal margin. The lower edge is markedly convex in side view. The distal margin slopes steeply forward. The upper and lower margins are carinate over almost their entire length. The upper carina is sharp, with a single row of small serrated sharply pointed teeth. The lower carina is slightly less sharp, with a median row of granules which is accompanied by lateral rows of somewhat irregularly spaced perforated granules (sockets), becoming more conspicuous near the base of the immovable finger The inner and outer surfaces of the hand are regularly and almost equally convex The outer surface is covered with widely scattered granules, mainly on the lower half. The inner surface is more evenly granulate, with the granules tending to become arranged in vertical rows near the lower margin The granulation is not visible on internal casts which show only muscle attachment pits. The immovable finger is slender, rounded in cross section, directed downwards at a very small angle, with a finely granulated prehensile edge near its base and one or two small triangular teeth on its proximal part There is no appreciable variation in shape or ornamentation. Two small chelae which were found in the Pebble Point beds are more elongate and their granulation and carination is weaker than in the typical *C bakeri* The two aberrant specimens cannot be definitely assigned to the common species here described.

Remarks—This species resembles *C mensiesi* Withers from the Middle Eocene (Scotland beds) of Barbados, and *C panamensis* Glaessner (*C. elongata* Rathbun, *non* Fritsch) from the Culebra formation (Middle to Upper Oligocene) of Panama. It differs from *C. mensiesi* in the more convex lower margin, the straight proximal margin, and the ornamentation of the surface. *C panamensis* has a more strongly inclined distal margin and also a different ornamentation Figures and descriptions of other elongate *Callianassa*-chelae such as *C erecta* Bohm, *C nuda* Beurlen, *C songoensis* Bohm, *C. longa* Noetling, *C. delta* Rathbun and *C brazoensis* Stenzel have also been compared but were found to differ from *C bakeri* either in the character of the margins or in details of the ornamentation. It is remarkable that most of the chelae of this type were found in Lower Tertiary deposits.

CALLIANASSA *cf* LACUNOSA Rathbun.

(Plate 1, fig 6a, b)

cf 1918 *Callianassa lacunosa* Rathbun, U S Nat Mus Bull 103, p. 138, pl. 59, figs 8-11 (Culebra formation Panama, Middle to Upper Oligocene).

cf. 1926 *Callianassa lacunosa* Rathbun, Withers, Geol Mag, vol 63, p. 105, pl 9, figs 3, 4 (Scotland beds, Barbados, Middle Eocene)

cf. 1935 *Callianassa halli* Rathbun, Geol Soc Amer, Spec Papers No 2, p. 72, pl 15, figs 30-35 (Midway group, Arkansas, Paleocene)

Distribution—Eocene, Rivernook Bed, south of Rivernook House, on coast about 1¼ miles south-east of the mouth of the Gellibrand River, Victoria.

Collection—Geology Department, Melbourne University, No. 1923 (coll. Mr. G. Baker).

Material—One incomplete right hand.

Description—Upper and lower margin strongly convergent, lower and proximal margin forming a right angle. Outer surface evenly convex, with a short ridge at the base of the immovable finger; inner surface almost flat but somewhat inflated above the middle. Upper edge carinate, smooth, with a row of eight small sockets below the rim on the inner surface. Lower edge not well preserved, possibly granulate. Few scattered granules on both sides of the lower part of the hand. The measurements of this specimen are as follows: Upper margin 8.5 mm., lower margin 8 mm., proximal height 8 mm., distal height 7 mm., length at the level of the interdigital sinus 8.5 mm., thickness 3.4 mm.

Remarks—This species is remarkably close to the American species *C. lacunosa*, of which *C hulli* is probably a synonym. The ornamentation of the inner side of the propodus is a very striking feature which does not occur in other species of the genus. The present specimen differs, however, in the marked convergence of the upper and lower margins and in the shorter infradigital ridge

CALLIANASSA sp

(Plate 1, fig 7a, b)

About eight hands and a dactylus of a *Callianassa* from the Rivernook locality represent another species which is undoubtedly distinct from *C. bakeri* and *C lacunosa* A small right and a left hand were found close together and belonged evidently to the same individual. These remains are unfortunately not sufficiently well preserved for a complete description of specific characters and no species name will be proposed for them.

The hand is short and high, with the upper and lower margins straight and sharply keeled and converging only slightly toward the distal margin. The proximal and distal margins converge more pronouncedly downward. The outer surface is moderately convex The inner surface is generally flat, with a broadly rounded crest along its central part. The immovable finger, which is incompletely preserved, is compressed at its base, with its upper edge sloping rapidly downward and with a rounded ridge extending a short distance below the articulation of the dactylus. There are about 10 weak granules scattered about the outer surface of the propodus near the base of the immovable finger. The inner surface shows a row of circular pits just above the lower margin, with two parallel rows of smaller and more widely scattered pits above it. The measurements of the largest specimen which is preserved as an internal cast are as follows: Upper margin 10 mm., lower margin 9 mm., proximal margin 10 mm., distal margin 9 2 mm, greatest height 10 25 mm., thickness 3.7 mm.

A dactylus was found in a small rock specimen about one-half inch from a propodus of which only an external mould remains. It is compressed and high, with a thin upper keel and a sharp prehensile edge with a toothlike projection near its base. There are three or four large circular pits just below the upper edge.

A small chela in which the immovable finger is preserved represents a third species of *Callianassa* from the Rivernook Bed. It resembles *C. bakeri* in its elongate shape, but differs in the straight lower margin and straight finger, and does not show the characteristic ornamentation of the species from the Pebble Point beds.

Genus **Ctenocheles** Kishinouye, 1926.

1914 ?*Pentacheles*, Balss, Abh K. Bayer, Akad Wiss, II Suppl-Bd., 10. Abh., p 75 (Cheliped only)
1926 *Ctenocheles* Kishinouye, Annot Zool Japon, vol 11, p 63.
1935 *Ischnodactylus*, Rathbun, Geol Soc Amer Spec Papers Nr. 2, pp. 63-65 (*non Ischnodactylus* Pelseneer)
1939 *Thaumastocheles*, Beurlen, Palaeont Zeitschr, vol 21, p 137 (*non Thaumastocheles* Wood Mason)
1945 *Ctenocheles*, Melbourne Ward, Mem Queensland Mus, vol 12, p. 134
Genotype, *C balssi* Kishinouye

Four isolated, long, thin, denticulate fingers, lying on a small rock specimen from the Rivernook locality, closely associated and partly overlapping, and evidently belonging to a single individual, are assigned to *Ctenocheles*. This genus was established for a living Thalassinid corresponding in essential features with *Callianassa*, but distinguished by the excessive development of the right cheliped which resembles that of the lobster-like deep-sea Decapod *Thaumastocheles*, but differs in the external position of the dactylus, the smooth propodus and the arrangement in a single plane of the denticles on the fingers. The type species was found in deep water off Japan. Recently another species was described from Moreton Bay, Queensland. It appears now that several species of Decapod claws from the Lower Tertiary of Alabama, Mississippi and Hungary, described under different generic names, belong to this genus.

CTENOCHELES VICTOR nov spec

(Plate 1, figs 8, 9)

Diagnosis—Fingers of the large chela very thin and long, with regularly alternating longer and shorter curved and pointed teeth, those of the small chela with a row of granules and with the distal ends curved

Distribution—Eocene, Rivernook Bed, outcrop south of Rivernook House, on coast about 1¼ miles south-east of the mouth of the Gellibrand River, Victoria.

Collection—Geology Department, Melbourne University, Nos 1925, 1926 (coll. Mr. W. J. Parr).

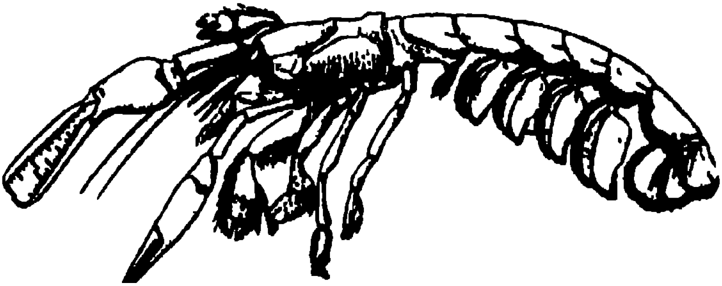
Material—Four fingers of the first pair of chelipeds belonging to one individual. As the fingers are lying in different directions and are overlapping each other, they were partly damaged and partly left concealed when the rock specimen containing them was split open.

Description—Both fingers of the larger cheliped are laterally compressed, long, thin, and straight. The base of the immovable finger is preserved, but its tip is not clearly visible Its length is approximately 13 mm. The distal end of the dactylus is broken off and the proximal end is concealed. As preserved, its length is 14 mm. In both fingers the prehensile edge is armed with a row of pointed conical teeth. On the dactylus about 5-6 slightly curved long teeth (over 1 mm.) are visible; they are regularly spaced, with about three shorter teeth (less than ½ mm.) in each interval. The arrangement on the immovable finger seems to have been similar. There are indications that this finger was directed slightly downward, forming an angle with the lower edge of the propodus, which however is not preserved.

The fingers of the smaller cheliped are rounded in section, with a row of granules of slightly varying size on the prehensile edges and several rows of widely spaced pores on the surface of the immovable finger. The distal ends are distinctly curved. The length of the immovable finger of the smaller cheliped is 7 mm.

Remarks—The preservation of the fingers of the first pair of chelipeds without any traces of other parts of the integument is undoubtedly due to the characteristic weak calcification of the burrowing Callianassidae. The remains of the animal must have been buried before it disintegrated and the more strongly calcified fingers were apparently shifted out of their original position as a result of some slight subsequent disturbance of the embedding sediment.

Ctenocheles victor differs from the living Australian *C. collini* M. Ward in the slender shape of its fingers. It resembles very closely *C. balssi* (fig. 1), but the teeth on the larger fingers are more regularly arranged, and the ends of the smaller fingers are more distinctly curved. The incomplete chelae from the Middle Oligocene of Hungary which Beurlen (1939) described as *Thaumastocheles rupeliensis* possess the distinctive features of *Ctenocheles*. Beurlen drew attention to their striking resemblance with the cheliped described by Balss as *Pentacheles* sp ?, but overlooked the fact that Kishinouye had proved that this fragment belonged to the type species of his new genus. The fragmentary hands and fingers described by Rathbun (1936) from the Paleocene and Eocene of Alabama and Mississippi as *Ischnodactylus* (*I. cockei, I. cultellus, I.? dentatus*) also agree with *Ctenocheles* in their shape and weak ornamentation and calcification; the denticulation of most of these fingers is incompletely preserved. It should be noted that their identification with *Ctenocheles* does not affect other species of *Ischnodactylus* such as the Cretaceous *I. macrodactylus* (Schlüter) and *I. esocinus* (Fritsch), in which long spiny claws are associated with lobster-like remains of the carapace or abdomen. Long fingers with long pointed teeth occur in more than one family of Decapod Crustacea, but the shape, calcification and ornamentation of the hand and fingers make it possible to distinguish them.



BURROWS OF *Callianassa* IN THE PEBBLE POINT BEDS

A peculiar type of cylindrical structures, obviously of organic origin, occurs in great abundance in the Pebble Point Beds at Buckley's Point and attracts attention, particularly on weathered surfaces (Plate 1, fig. 10; Plate 2, figs. 1-5). The friability of the rock makes it difficult to collect satisfactory specimens or to take reliable measurements. The following observations on these structures were made in the lowest beds resting on the eroded surface of the Jurassic at Buckley's Point, one half-mile north-west of Pebble Point, and along the coastal outcrop of the gritty beds north-westward towards Point Margaret. The tubes vary in size, but most of them are between ½ inch and one inch thick. They are mostly fairly straight, occasionally bifurcating, and lying either parallel to the bedding planes or at right angles to them or in various other directions Their length could not be measured as they become clearly visible only as portions of them weather out of the rock They are eroded away soon after their emergence from the matrix. Blind ends of the tubes are seen occasionally. Most of the specimens collected are formed from more fine-grained material than the immediately surrounding matrix, but sand grains occur in the filling of the tubes Significant characters of these structures which distinguish them from the mud-filled worm burrows commonly occurring in marine sediments can be summarised as follows —(1) Generally straight course, with more or less angular changes in direction; (2) bifurcating but not arborescent branching; (3) limited size-range; (4) smooth surfaces, without agglutination of pellets or foreign bodies to form walls; (5) occurrence of blind ends.

These features, taken in conjunction with the common occurrence of *Callianassa bakeri* in the same beds, suggest a burrowing Crustacean, and in all probability this species of *Callianassa*, as the originator of the burrows The size of the *Callianassa*-claws is in reasonable agreement with the average size of the tubes. Taking the Recent *C. aequimana* W. H Baker from the coast of South Australia as a standard, an arbitrary procedure which seems justified in view of the resemblance in the proportions of the claws with those of *C bakeri*, it is found that in this Recent species a propodus 7 mm long on its upper edge (equal to the smaller specimens of *C bakeri*) corresponds to a carapace and abdomen about 12 mm. wide. This is in good agreement with the size of the four specimens of tubes collected in situ. Claws as well as tubes seem to range to about twice this size.

Fossil burrows of *Callianassa* were described in detail by K Ehrenberg (1938) from the Lower Miocene of the Vienna Basin. Their essential characters agree well with those of the structures here discussed. A claw of *Callianassa* was discovered in the blind end of one of the tubes from the Vienna Basin locality. In his publication, Ehrenberg discussed the available information on the habits and habitat of *Callianassa* and allied forms. It is well known that the Callianassidae live in deep burrows in muddy or sandy sediments. According to Stevens (1929), *Callianassa*-burrows are very similar to those of *Upogebia*, which are described as 20-40 mm. in diameter, nearly vertical, and Y-shaped or U-shaped with two or more branches opening at the surface and with one or more short blind passages

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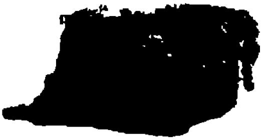
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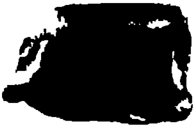
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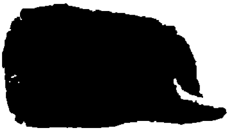
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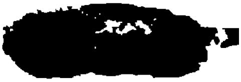
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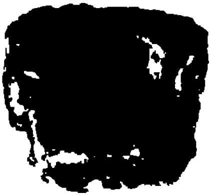
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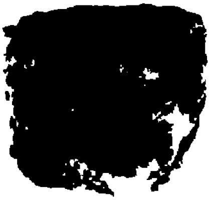
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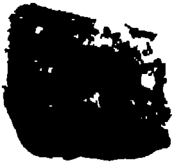
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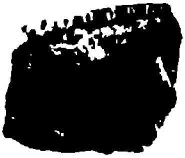
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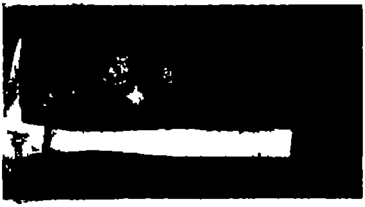
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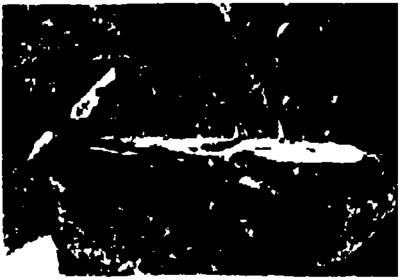
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extending down or to the side They were found either scattered or so close together that the mounds of debris deposited in heaps around the openings actually touched each other As a result of the pressure of the animal s body in the great many trips back and forward the walls are smooth as if plastered Judging from a comparison between these descriptions and the field observations made to date it appears likely that the abundant fossil burrows in the Pebble Point Beds were made and inhabited by *Callianassa*

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Descriptions of Plates

PLATE I

Callianassa bakeri nov spec

Fig 1a c—Right propodus *a*—outer view *b*—inner view *c*—upper view × 2 66 [M U G D No 1918]

Fig 2—Left propodus outer view × 2 [M U G D No 1919]

Fig 3a b—Left propodus *a* inner view *b*—outer view × 2 [M U G D No 1920]

Fig 4a b—Left propodus *a* outer view *b* inner view × 2 [M U G D No 1921]

Fig 5 Left propodus part of external mould of inner surface with immovable finger × 3 5 [M U G D No 1922]

Callianassa cf *lacunosa* Rathbun

Fig 6a b Right propodus *a* outer view *b*—inner view × 2 66 [M U G D No 1923]

Callianassa s

Fig 7a, b—Internal cast of right propodus *a* outer view *b* inner view × 2 66 [M U G D No 1924]

Ctenocheles victor nov spec

Figs 8 9—Four fingers in two counterpart blocks of matrix The two fingers of the larger cheliped are visible in the middle and lower part of Fig 8 and in the centre of Fig 9 The two fingers of the smaller cheliped are above one is lying on the surface while the other is split open in the specimen of Fig 8 and visible in cross section only above and to the left of the centre of Fig 9 Fig 8 × 3 3 [M U G D No 1926] Fig 9 × 3 [M U G D No 1925]

Callianassa sp

Fig 10—Burrows weathering out of a block of Pebble Point grit at Buckley s Point The hammer handle is 11 inches long

PLATE II

Burrows of *Callianassa* sp (Natural casts)

Figs 1 4—From Buckley s Point coll M F Glaessner Nat size [M U G D Nos 1927 30]

Fig 5—Burrows weathering out of a block of Pebble Point grit, Buckley s Point

Figs 6 7—From the Miocene of the Vienna Basin After K Ehrenberg 1938 pl 28 figs 4 6 2/3 nat size

Photographs Plate I figs 1 9 and Plate II figs 1 4 by Miss M L Johnston Geology Department Melbourne University Originals in the collection of the Geology Department

2—A New Trilobite from the Yeringian (Lower Devonian) Rocks of Kinglake, Victoria

By EDMUND D. GILL, B.A., B.D.

[Read 13th June 1946]

Abstract

Dicranurus kinglakensis sp nov is described and compared with *D longispinus* (Mitchell) from New South Wales and *D monstrosus* (Barrande) from Bohemia The homologies of some parts are discussed especially the genal spines The Victorian beds containing *Dicranurus* are shown by the accompanying fossils to be Lower Yeringian in age *Dicranurus* occurs in Devonian beds except that in New South Wales *D longispinus* is found in beds referred to the Silurian The standing of the sub genus *Bounyongia* is discussed

Introduction

In the Kinglake District of Victoria there is a large synclinal structure in which is preserved a series of marine sediments of Lower Devonian age From Davies Quarry on the western branch of Stony Creek about a mile north of the Kinglake West State School a rich faunule including the new species now described has been discovered

Classification

The definition of the family of trilobites to which the new species belongs has been the subject of much debate However as a result of the researches of the Richters (1917 1928 1930) Reed (1925) Warburg (1925 1933) and others some general agreement appears to have been reached The following classification has been adopted

Order OPISTHOPARIA Beecher 1897

Family ODONTOPLEURIDAE Burmeister 1843

Genus **Dicranurus** Conrad 1841

DIAGNOSIS—Odontopleurids with lobes isolated by well developed false furrows from central part of glabella small first lobes large second and third lobes and small fourth (occipital) lobes median post glabellar projection (of occipital origin) produced into two long posteriorly directed recurved spines Cephalon more or less semicircular free cheeks not anchylosed with fixed cheeks eyes post central Thorax with nine segments (not proved in genotype but inferred from *D kinglakensis*) the pleurae characterised by elevated ridge divided unequally by a furrow into a narrower anterior part and a wider posterior part and extended distally into spines of unequal size corresponding with the pleural ridges in position and relative size Pygidium with two long spines

Dicranurus is very like the genus *Ceratocephala* but in the latter the occipital spines are shorter straight divergent and separate at their bases (i e not fused into a median post glabellar projection), the free cheeks are anchylosed with the fixed cheeks the cephalon is broader anteriorly than posteriorly the eyes are pre central the pleurae are divided into equal parts by the median furrow

DICRANURUS KINGLAKENSIS, sp nov

(Plate III figs 1 3)

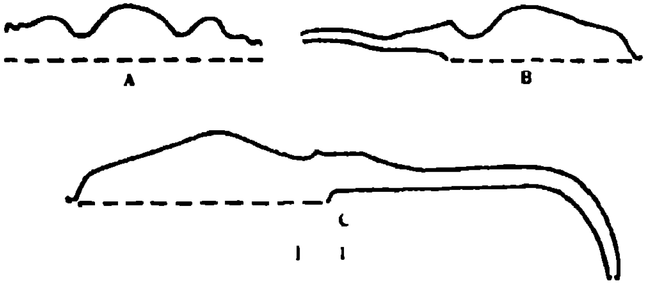
TYPE MATERIAL—A holotype consisting of the cast of a carapace complete except for damage to the front of the cephalon The matrix in which it is preserved is a bluish grey indurated shale with a thin band of brownish grey sandstone on the opposite side of the slab from that preserving the fossil University of Melbourne Dept of Geology reg no 1936 collected and presented by Mr A A Brunton A paratype consisting of a cranidium in the same matrix collected and presented by Mr O P Singleton B Sc M U G D reg no 1937

Both holotype and paratype were collected from Davies Quarry west branch of Stony Creek Kinglake West Victoria

THE CARAPACE—(described from holotype pl III fig 1) is 6 5 cm long (anterior margin incomplete) and 4 cm wide exclusive in both measurements of the spines The general outline is roughly that of an ellipse with the longer sides flattened The carapace is strongly trilobed and very spinose The surface is covered with tubercles large and small In life the cephalon must have been on a different plane from the thorax in order to allow room for the recurved occipital spines

THE CEPHALON—(1) *The cranidium* (described from the paratype pl III fig 2) in its outline is characterised by almost straight lines The sides of the cranidium make an angle of approximately 120° with the anterior margin The posterior lateral angle of the cranidium is approximately 50 Supporting the median post glabellar projection (characteristic of this genus) is a flat bracket (on each side) the outer border of which makes an angle of 35 with the median longitudinal axis of the cranidium This bracket is fused to the fixed cheek and passes over the level of the lateral extensions of the occipital segment at about half way between the posterior lateral angle of the cranidium and the median post glabellar projection This bracket carries the fourth lateral (occipital) lobe which is small The median post glabellar projection (Reed s post central lobe) is about three quarters of the length of the median area of the glabella It bears posteriorly two long curved hollow spines the bases of which coalesce to form the post glabellar projection

The false furrows of the glabella are relatively wide (1 5 mm) and deep and are parallel The median lobe is thus rectangular in outline The second and third lobes are sub equal and relatively large and well developed but the first and fourth (occipital) lobes are small and little elevated The degree of tumidity is shown in fig 1B which is a longitudinal silhouette of the paratype cranidium and fig 1A



I 1

which is a transverse section of the same The silhouette is given rather than a median section, so as to show the configuration of the occipital spines

The spines on the fossils described in this paper usually have a median furrow due to collapse such as is found in thin hollow shells like *Styliolina* (Gill, 1941) They have also fine transverse markings The occipital spines bear tubercles

The axial glabellar furrows ('true furrows") are but weakly developed anteriorly although more strongly so posteriorly A well-marked furrow borders the lateral margins of the cranidium Another specimen (National Museum reg nos 14522 and 14523, which are counterparts) shows a similar furrow constituting a pre glabellar field on the cranidium The furrow and ridge of the occipital segment are well displayed at their lateral extensions outside the brackets already described

The surface of the cranidium is well tuberculated, a particularly prominent tubercle being present on the median post glabellar projection National Museum reg nos 14522 and 14523 show this tuberculation particularly well The tubercles show on both the cast and the mould proving that they involved the full thickness of the exoskeleton and were not merely external outgrowths There are prominent tubercles on all the raised parts of the cranidium, some also form a row up the fixed cheeks between the axial furrows and the marginal furrows Between the larger tubercles are numerous ones of smaller size

The median post glabellar projection is ¾ cm long and 6 mm wide It covers the first segment of the thorax before dividing into two strong, hollow spines These are 2 mm in diameter at the cephalic end, and circular in cross section They diverge at first so as to make an angle of 40° between their axes then become more parallel (see Pl III fig 2) Only 1 cm of the spines is preserved in the paratype However other specimens show that they were recurved, as is characteristic of *Dicranurus*, but not spirally as in *D monstrosus* they are more like the occipital spines of *D longispinus* (fig 1C shows the spines on a large specimen Melb Univ Geol Mus reg no 1917)

(2) *Free Cheek* (described from M U G D reg no 1938 Pl III, fig 3) Width from margin immediately anterior to eye to margin immediately anterior to genal spine, 11 5 mm Length taken at right angles to last line and on genal angle side of eye, 12 mm Outer margin of cheek smooth, roundly curved, drawing in under the genal spine, which rises on the dorsal surface of the cheek instead of being a projection of the genal angle The spine arises only 3 mm from the inner margin of the cheek It is about 7 mm wide where it arises, but narrows quickly to 4 mm and is about 3 mm wide when it passes off the cheek From its point of genesis to where it is broken off, the spine is nearly 3 cm long The spine is a little over 1 mm wide where it is broken off but as it is a hollow structure crushed, this may not have been the original diameter

The eye is raised on a short stumpy pedicel about 2 5 mm wide at its base (longest diameter) The pedicel narrows a little before expanding at the top where it terminates in a highly curved visual area which looks oval to round from the dorsal aspect The free cheek is tuberculated the tubercles being grouped mostly round the base of the pedicel and around the outer margin Another specimen an internal cast shows the visual area to consist of numerous sub-hemispherical bodies (casts of inner surfaces of the lenses) much less than their own diameter apart The eye consisted therefore of closely packed strongly convex lenses There are 12 lenses per millimetre so there must have been some hundreds in the complete eye There is a definite rim in this specimen where the visual area begins The pedicel is about 1 mm high and the visual area approximately the same

The cranidia and the free cheeks show that the eyes were situated opposite the anterior end of the third glabellar lobe and so post central —a distinguishing feature from the closely allied genus *Ceratocephala* In most cases the free cheeks and cranidia are found separate whereas these parts are fused together in *Ceratocephala* and so the cephalon is usually found whole

THE THORAX—(described from holotype) consists of nine segments The thorax is more or less even in width (about 4 cm) until the 7th segment from whence the width is reduced gradually to align the margin of the thorax with that of the pygidium The axis is prominent (anteriorly 1 cm wide or 1 5 cm including nodules) and tapers posteriorly proportionately with the pleurae Anteriorly the axis rises 4 mm above the most elevated part of the pleurae Nodules clearly developed they are associated with the broader posterior ridge of each pleuron

The part of the pleurae in evidence from the dorsal aspect of the trilobite consists of a broad raised ridge divided by a shallow furrow into a wider posterior part and a narrower anterior part the latter being roughly half the width of the former Each pleuron is extended distally into two spines—a narrow short anterior one and a wider long posterior one Probably the relative development of these spines is connected with the relative size of the subsidiary ridges on the pleurae It would appear from the holotype that the posterior spines are only of the order of a centimetre in length on the first three pleurae and deflected backwards at an angle of the order of 45° to the longitudinal axis of the trilobite whereas on the succeeding pleurae there are long strong spines up to 4 cm (and perhaps more) in length deflected so as to be approximately parallel with the longitudinal axis The spines on the fourth and fifth segments are the longest The respective length of the spines seems to be connected with their protective function when the trilobite is enrolled

The thorax is tuberculate there being two prominent tubercles on each segment of the axis one in the middle of the wider subsidiary ridge of each pleuron one where the heavier posterior spine is deflected and sometimes others on the spines

PYGIDIUM—(described from holotype) Small and sub triangular in outline Greatest width 2 5 cm and greatest length 0 8 cm Three segments are discernible on the axis declining in definition anterior-posteriorly The segments have two tubercles on them as in the thorax The axis is about half the length of the pygidium, well rounded terminally and standing about 3 mm above the rest of the pygidium The most anterior segment has nodules on each side of the axis and is produced into well defined pleural ridges with strong furrows on each side At about half the distance to the margin, the ridges are deflected backwards very strongly and are produced beyond the margin into long strong spines which are directed almost parallel to the longitudinal axis of the trilobite The ridges on the pygidium have a central tubercle on them as do their homologues in the thorax the pleurae Apart from the spines the margin of the pygidium is smooth

Specific Comparisons

The new species is compared with the following forms

(1) *Dicranurus longispinus* (Mitchell 1889 Etheridge and Mitchell 1896) Pl III fig 4 Etheridge and Mitchell referred this species to *Ceratocephala* but it does not belong there because the free and fixed cheeks are not fused the occipital spines are not straight and separate at their bases (it has a post glabellar projection) and the pleurae are not divided into equal areas by the pleural furrows The form on the other hand has all the diagnostic features of the genus *Dicranurus*

The type material has been examined and found to be very similar to our new species Just as *Gravicalymene australis* (Etheridge and Mitchell) *G angustior* (Chapman) and *G cootamundrensis* Gill constitute a closely related gens so do *Dicranurus longispinus* and *D kinglakensis* The new species is distinct from Mitchell s species in that it is altogether a more developed form of heavier build This is illustrated in the following features

- a *Dicranurus kinglakensis* is typically much bigger than the latter Comparison of a number of specimens shows it to be one third or more larger
- b The carapace is more tumid (up to twice the elevation)
- c It is more heavily tuberculated
- d The eyes are more prominent
- e Proportionately the thoracic rachis is wider The ratio width of rachis over width of thorax is 4 4 8 for *D kinglakensis* and *D longispinus* respectively
- f The pygidium is more robust in the former species The ratio width over length for the two species is 2 6 3 15 respectively The pygidial spines are proportionately stronger

Dicranurus kinglakensis is a more developed form than *D longispinus* and from this it may not be wrong to infer that it comes slightly later in the evolutionary sequence Its stratigraphical position is discussed on page 13

(2) *Dicranurus monstrosus* (Barrande 1852) The cranidium of this species is very like that of *D kinglakensis* except that there is a marked difference in the spines The original figure of Barrande (1852 Pl 37 fig 34) and the photographs reproduced by Rud and E Richter (1930 fig 6) show that there is a difference of about 20° in the divergence of the spines also the spines in our species and that of Mitchell curve downwards and perhaps a little outwards (although this may be due to crushing) but they are not spirally

recurved as are those of *D. monstrosus*. There are no branches on the spines of our species as figured for Barrande's species (R. and E. Richter, 1917, fig. 7). The eye pedicels of *D. monstrosus* are longer than in the new species.

(3) *Dicranurus hamatus* Conrad (1841). This species is the genotype for the genus *Dicranurus*, and comes from rocks of Lower Helderberg age. The figures vary somewhat, but apparently the lobation is much less distinct than it is in our species. The eyes in *D. hamatus* are situated much further back (Clarke, 1892, Pl. 1, fig. 6) than in *D. kinglakensis*. Moreover, the thoracic segments are of an altogether different construction, as also is the pygidium, if those figured by Hall (1861, Pl. 79, fig. 19) have been proved to belong to that species. It is interesting to note that each segment of the axis bears two tubercles (considered to be homologous with the occipital spines), an arrangement which holds for the species of *Dicranurus* known so far.

(4) *Dicranurus limenarcha* Clarke (1905) has only a superficial resemblance to the new species.

Associated Fauna

The following forms are associated with *Dicranurus kinglakensis*:

ANTHOZOA	*Lindstroemia ampla* Chapman.
	L. yeringae Chapman.
	Pleurodictyum megastomum Dun.
	Pleurodictyum sp. nov.
BRACHIOPODA	*Anoplia australis* Gill.
	A. withersi Gill.
	Dalmanella aff. *elegantula* (Dalman).
	Eospirifer sp.
	Leptaena rhomboidalis (Wilckens).
	Nucleospira australis McCoy.
	Orbiculoides sp.
	Plectodonta bipartita (Chapman).
PELECYPODA	*Nuculites maccoyianus* Chapman.
	Palaeoneilo sp.
TRILOBITA	*Homalonotus* sp.
	Leonaspis sp.
	Odontochile sp.
	Proetus sp.
	Scutellum sp.
OSTRACODA	*Beyrichia* sp.
	Plumulites sp.
ECHINODERMATA	*Rutroclypeus* sp.

There were also collected starfish, brittlestars, carpoids, crinoids, and polyzoa which have not been determined yet.

Stratigraphical Inferences

Anoplia of two species in good numbers and plentiful *Plectodonta bipartita* indicate a Lower Yeringian age (Gill, 1945). The rest of the faunule fits in well with this age determination. The type Yeringian sandstones, shales, and mudstones have been shown to be

Lower Devonian in age (Gill, 1942). *Dicranurus, Pleurodictyum* (two species present), and *Plectodonta* of the *P. comitans* type (cf. *P. bipartita*) are Devonian forms in overseas faunas. *Dicranurus kinglakensis* is very close to *D. monstrosus* from Étage G of the Bohemian Devonian. The present writer has previously drawn attention to the affinities between the Bohemian Devonian fauna and the Yeringian faunas of Victoria. This is well illustrated in the case of the trilobites, as the following table shows:

Victorian Form	Compared Bohemian Form	Étage
1 *Acanthopyge australis* (McCoy)	*A. haueri* (Barrande)	F
2 *Calymene killarensis* Gill	*C. blumenbachi* Brongniart	E F
3 *Cheirurus* aff. *gibbus* Beyrich	*C. gibbus* Beyrich	F G
4 *C. sternbergi* (Boech)	*C. sternbergi* (Boech)	E F G H
5 "*Dalmanites meridianus*" Eth. & Mitch	*D.* (=*Odontochile*) *hausmanni* Brongniart	G
6 *Gravicalymene angustior* (Chapman)	*G. interjecta* (Corda)	F G
7 *Phacops fecundus* Barrande	*Phacops fecundus* Barrande	E F G H
8 *Scutellum greeni* (Chapman)	*S. formosus* (Barrande)	G

The above determinations are not all according to modern standards; e.g.. the *Phacops fecundus* found here varies from that found in Bohemia. The name *Dalmanites meridianus* has been used by various authors to cover a closely related series of forms referable to the genera *Dalmanites* and *Odontochile* The form at Kinglake is an *Odontochile*. Nevertheless, the similarities are striking and not without significance.

On the other hand, the Yeringian fauna is not one completely of Bohemian aspect. As already shown (Gill, 1942), there are affinities with other Boreal faunules, especially in North America.

Our new species of *Dicranurus* is very close also to *D longispinus* from the Hume Series in New South Wales, which have been referred *in toto* to the Silurian (Brown, 1941). The bed containing *Dicranurus* also contains *Pleurodictyum,* although Dr. Brown is of the opinion that the N.S.W. form is not comparable with the genotype (personal communication).

Palaeozoological Features

SPINES. The high degree of spinosity of *Dicranurus kinglakensis* is a notable feature. The spines are hollow, and so aided a floating habit for this trilobite. They would be lined by at least one layer of cells, because the spines are part of a secreted exoskeleton, but the centre may have been occupied by light parenchymatous tissue or a blood sinus.

The considerable surface area of the numerous spines would provide a good deal of friction with the water, and thus aid floating, just as the appendages of some crustacean larvae do. The action may be compared with a snowshoe preventing sinking into snow, or the large surface area of a camel's foot-pad preventing sinking into sand.

Such spinosity of trilobites is frequently associated with the elevation of the eyes on pedicels. Both are adaptations to a planktonic habit. The spines helped to keep the animal afloat, and the eyes on pedicels more readily descried danger. A trilobite half obscured in the mud of the sea floor did not need the sharp lookout necessary for a planktonic form. One notes the large eyes of crustacean larvae and other forms of marine plankton. When danger came, the trilobite rolled itself up, presenting the enemy (in the case of *Dicranurus*) with a chitinous spheroid well armed with spikes. The spines may thus be regarded as having a protective as well as a flotation function. A third function is that of balancers, like the outriggers on Pacific islanders' canoes. This would apply particularly to the big outstretched genal spines of *Dicranurus*.

The radial arrangement of the spines in the genus *Radiaspis* suggests that it was adapted for floating without locomotion. In *D. kinglakensis* and *D longispinus* (the only species of the genus where the complete thoraces are known) the long thoracic spines and the pygidial spines are carried backwards in a streamlined fashion. This is clearly an adaptation to floating *with* locomotion. The movement, however, would be in one direction only. The adaptation was for forward movement, the deflection of the spines being disadvantageous for any quick backwards movements as seen in some modern crustacea. (It is not suggested that the Trilobita should be classified as Crustacea.) One imagines *Dicranurus* floating among the plankton or swimming gently forwards. Like the rest of the Odontopleuridae, it is highly adapted and specialised. Other Odontopleurids are present with the new species, but material good enough for description was not collected.

It is imagined that the spines would complicate moulting As the spines would have to be renewed at each ecdysis, cells capable of secreting a new exoskeleton must have lined the inner surface of the spines. At moulting, the newly forming spines would need to be withdrawn from the old ones As apparently the animal emerged from the front of the old armour, the backwards deflected spines would be easier of egress than the radially orientated spines of *Radiaspis*, or the long, slender curved spines of *Ancryopyge*

OCCIPITAL STRUCTURES. The interpretation of the median post-glabellar projection with accompanying brackets and spines as occipital structures (Warburg, 1933), seems to have found acceptance rather than their interpretation as glabellar ones (Reed, 1925). The study of the Australian species of *Dicranurus* brings support for Warburg's view, it being possible to demonstrate the intimate relationship between the obvious part of the occipital segment, the post-glabellar projection and the brackets.

The brackets carrying the occipital lobes illustrate a well-known architectural principle for buttressing a member carrying heavy strain. The long occipital spines must have transferred considerable strain to the projection carrying them. The projection stands about 3 mm. above the lateral extensions of the occipital segment in *D. kinglakensis*, and projects back half a centimetre over the thorax. The brackets provide excellent support for this structure which needs it in view of the relatively big strain carried. The brackets link the fused bases of the spines (i.e., the post-glabellar projection), the lateral extensions of the occipital segment, and the glabella and fixed cheeks.

I agree with Warburg in considering the occipital spines homologous with the tubercles on the occipital ring *Dicranurus kinglakensis*, like all other species of this genus of which the thoracic segments are known, has two tubercles in a like position on the axis of each segment of the thorax and pygidium Judging by the faint tubercles on the pygidium of *D longispinus*, the same arrangement probably existed there The very prominent tubercle behind the median glabellar lobe in *D monstrosus D longispinus*, and *D kinglakensis* may be regarded as an incipient spine

Writers have drawn attention to the fact that the cephalon and thorax of *Dicranurus* could not have been in the same place, because of the large occipital spines curved down below the level of the cephalon The orientation of the trilobite must have been therefore one of the following

(a) For the thorax and pygidium to form an obtuse angle with a horizontal cephalon (the angle would be of the order of 140°-150° in the case of *D kinglakensis*) This would considerably increase friction with the water in locomotion, and decrease the friction assisting flotation The same would apply to a partially enrolled condition The thorax and pygidium could have been horizontal and the cephalon inclined downwards, this would interfere with rear vision

(b) For the thorax and pygidium to be curved so that the dorsal surface of the trilobite was concave, a stance illustrated for *Ceratarges* by R and E Richter (1930, fig 5) This arrangement (if not extreme) would produce less friction in locomotion than (a), and would affect the animal's flotation to no appreciable extent This appears to me to be the more likely attitude of the animal in life, as it is a better adaptation

However it is difficult to imagine how the occipital spines were accommodated in *D monstrosus* Clarke (1892 Pl 2 figs 1 2) and the Richters (1930, fig 6) show that these spines were recurved to an extreme degree, and so the animal must have remained partially enrolled, or its body must have been at nearly right angles to its head Both these attitudes are amazing, especially for a planktonic form This appears to be an example of a specialisation being carried to extremes, and so becoming a liability instead of an asset

It has been suggested that these occipital spines were the beginning, in this group, of the provision of a thoracic cover (cf extant crustacea) When *Dicranurus* was enrolled these strong long spines did provide some protection for the thorax, but they appear to have been a disadvantage when the animal was not enrolled

Genal Spines Reed (1925, p 423) has drawn attention to the phenomenon of genal spines which rise from the dorsal surface of the free cheeks instead of being projections of the genal angles as is usually the case He questions whether these genal spines are really homologous with the usual genal spines The alternatives appear to be

(a) That the spines are outgrowths of the rolls of the free cheeks, or the hypertrophy of tubercles thereupon One may compare here the probable origin of the occipital spines from tubercles on the occipital segment

(b) That the spines are true genal spines (being outgrowths of the margin of the exoskeleton in the same way as the thoracic spines are), but whose bases have extended back over the surface of the free cheeks.

I incline to the latter opinion (in the case of *D kinglakensis* at least), because there is no genal angle underneath the spine. A specimen giving a good lateral view of the free cheek shows that the lateral and posterior margins of the free cheek curve in quite strongly under the spine, rising to flow outwards as its ventral surface. If a free cheek with normal genal spine were made of plastic material, and the spine then pushed in towards the eye, the structure would simulate that found in *D. kinglakensis* If the spine in this species were an hypertrophy of a dorsal tubercle or otherwise an outgrowth of the dorsal surface of the free cheek, then one would expect to find a more or less normal genal angle, even if somewhat fused with the spine above.

PYGIDIUM. A point of interest in *Dicranurus* which one has not seen commented upon is that the deflection of the segments fused in the pygidium is not marginal (as in the thorax), but about half-way between the pygidial rachis and the margin of the pygidium. This suggests that in the fusion of the elements of the exoskeleton that form the pygidium, the coalescence extended beyond the pleurae so affected, and filled in between the deflected pleural spines, thus placing the angle of deflection upon the surface of the pygidium instead of at the margin. Such a deflection of segments in the pygidium is rare among trilobites.

Palaeoecology

Dicranurus kinglakensis occurs at Davies' Quarry, Kinglake, in a band where it is associated with a number of other trilobites. Not far from the trilobite band is a coral band in which *Lindstroemia* and *Pleurodictyum* predominate. Corals are an inconspicuous element in the trilobite band, and the trilobites a minor feature of the coral band In sorting out loose blocks on the floor of the quarry, one can readily say from which band each fossiliferous block comes The matrices appear to be the same, but obviously there must have been some definite ecological difference. The similar matrices show that there was a similar mud floor in each case. As the corals are affected so conspicuously, temperature may have been the variant. A warmer current may have encouraged the development of corals at one time, and a cooler current favoured the trilobites at another .

The structure of *Dicranurus kinglakensis* indicates that its habit was planktonic (cf. Ruedemann, 1934). It is remarkable how such forms are often limited in their geographical distribution as far as their apparent fossil occurrence is concerned *Dicranurus* has been found in the Kinglake area only of the Yeringian, just as *Acanthopyge australis* (McCoy) appears to be limited to the Killara area, although common there and a planktonic form (Gill, 1939). On the other hand, mud-loving trilobites like *Phacops* seem to be ubiquitous in the Yeringian Series

In Davies' Quarry there is a third band presenting yet another quite distinct assemblage. It is characterised by numerous echinoderms (carpoids, crinoids, and probably blastoids), asterozoa (starfish and brittle stars) and trilobites No starfish was found in the other two horizons, and the only echinoderms were crinoids

Note on the Subgenus Bounyongia

The referring of *Ceratocephala longispina* in this paper to the genus *Dicranurus* brings into question the standing of the subgenus *Bounyongia* (Etheridge and Mitchell, 1917 pp 497 8) The type specimens (Pl 26 figs 12 13 Pl 27 fig 14) have been examined, they are somewhat crushed They are not referable to the genus *Dicranurus* because the cephalon is broader anteriorly than posteriorly the free cheeks are fused to the cranidium the spine bases are separate and the eyes are pre central Cowper Reed has mentioned the imperfection of the specimens (1925 p 417) and Warburg (1933 p 14) has expressed doubt about the feature on which the subgenus was based i e the emergence of spines from the glabella After examining the specimens I am in agreement with Warburg that the spines are occipital and therefore present no new feature upon which a subgenus could stand Both specimens show a prominent central tubercle in the area between the central portion of the glabella and the spine bases such as is seen in *Dicranurus* As the subgenus was founded on a misinterpretation it must now lapse

Acknowledgment

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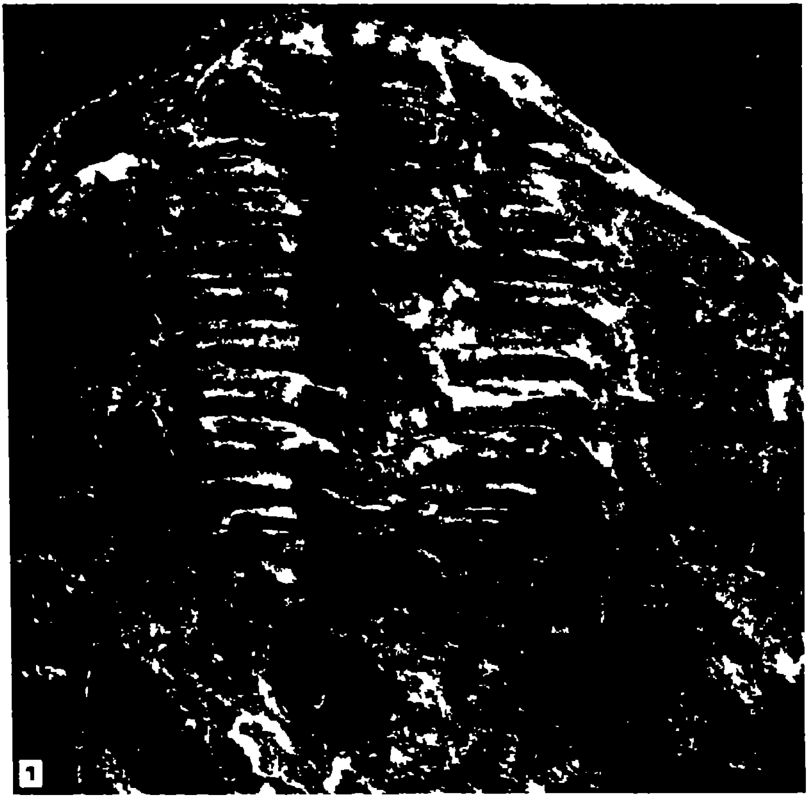
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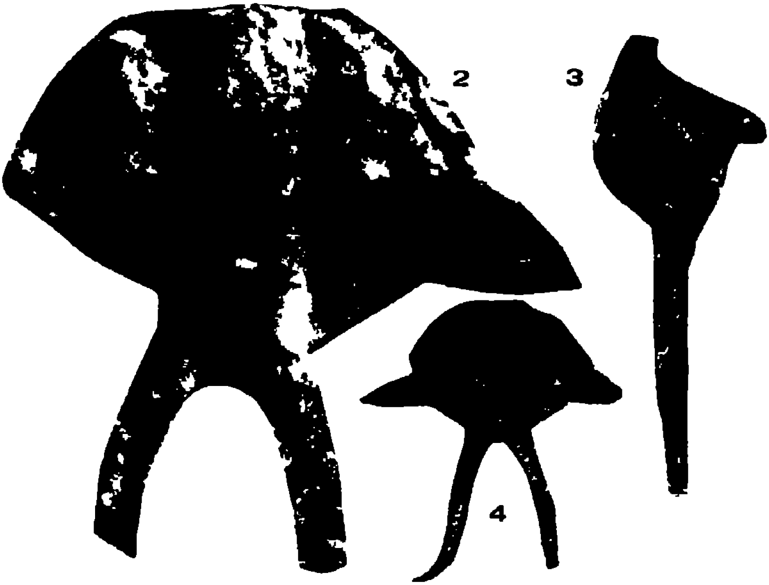
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Description of Plate

PLATE III

Fig 1—HOLOTYPE of *Dicranurus kinglakensis* sp nov × 1 7 approx
Fig 2 PARATYPE of *D kinglakensis* × 3 5 approx
Fig 3—PARATYPE Free cheek of *D kinglakensis*
Fig 4—HOLOTYPE of *Dicranurus longispinus* (Mitchell)
Photograph of specimen drawn in Etheridge and Mitchell 1893 Pl 34 fig 2 Reg No F 27 967 Australian Museum Sydney

3—A Fossil Crab from the Lakes Entrance Oil Shaft, Gippsland, Victoria

By IRENE CRESPIN, B A

[Read 6th June 1946]

Introduction

During the sinking of the Lakes Entrance Oil Shaft situated in the Parish of Colquhoun about 2 miles north east of Lakes Entrance township 198 miles east of Melbourne a very large quantity of sedimentary material was excavated and many well preserved fossils were discovered

The shaft was sunk to the depth of 1 212 feet and during operations a unique opportunity was afforded the palaeontologist to collect suites of fossils from the various stratigraphic horizons through which the shaft passed The writer paid frequent visits to the site to make observations on the stratigraphic sequence and to collect fossiliferous material At the same time members of the staff at the shaft were constantly on the watch for specimens of large fossils and it was due to the keenness of certain of these men that the remains of a fossil crab were discovered

Two carapaces and a chela were found at a depth of 1 000 feet in brown fine grained sandy and micaceous marls characteristic of the Janjukian Stage of the Middle Miocene in the Lakes Entrance Area (Crespin 1943) They were associated with an assemblage of micro fossils which are typical of Janjukian deposits elsewhere in Victoria

The discovery of remains of a decapod crustacean referable to the genus *Harpactocarcinus* in rocks of Middle Miocene age in Victoria is of some importance The only other crab previously recorded from the Victorian Tertiaries is *Ommatocarcinus corioensis* (Cresswell) which was found in the Miocene deposits at Corio Bay near Geelong (Cresswell 1886) It was considered that the genus *Harpactocarcinus* had a restricted range from Eocene to Oligocene Two species *H americanus* and *H rathbunae* have been recorded from the Eocene of Texas (Stenzel 1934) and one species *H tumidus* was described from the Upper Oligocene beds at Woodpecker Bay Brighton South Island New Zealand (Woodward 1876) However in a personal communication from Dr Marwick of the Geological Survey of New Zealand he stated that specimens of a crab probably referable to *Harpactocarcinus* had been discovered in beds of Middle to Upper Miocene age in New Zealand

The type specimens of *Harpactocarcinus victoriensis* are housed in the Commonwealth Palaeontological Collection Mineral Resources Survey Canberra

The plate which accompanies this paper has been prepared by Mr F Crisp of the Department of the Interior Canberra to whom I express my thanks

Description of Species

Order DECAPODA

Family XANTHIDAE

Genus **Harpactocarcinus** Milne Edwards 1862

HARPACTOCARCINUS VICTORIENSIS sp nov

(Plate IV figs 1 7)

HOLOTYPE Carapace preserved partly with armour in place and partly as internal mould Carapace very tumid from front to back especially in branchial and gastric regions Whole of surface finely granulated Frontal portion broken and partly obscured by matrix Frontal margin is narrow span between orbits measuring 15 mm Orbits are shallow and rounded Lateral angles of epibranchial border marked by blunt and rounded denticles The under side of carapace shows broad abdomen suggesting a female form The last segment of the abdomen is broadly triangular in shape Other segments are indistinct

Width of carapace 85 mm length from rostrum to posterior border 78 mm length along curve of carapace 90 mm greatest thickness 35 mm

PARATYPES *A* Carapace preserved chiefly as internal mould Carapace flatter than in holotype covered with fine granulations Posterior border broken Frontal portion also broken but indications are that rostrum short The divisions between the branchial cardiac and gastric regions are very slightly indicated by undulations of the surface of the carapace and by a slightly roughened and incised line petalloid in shape of short oblique markings on the side of the gastric region

On the under side the sternum is fairly well preserved The longitudinal median groove of the sternum shallow The first segment of the sternum is broadly V shaped from in front of the abdominal tip to the anterior margin of sternum The abdomen is not preserved The four pairs of simple monodactylous feet are present but have been broken

Width of carapace 89 mm length from rostrum to broken posterior border 75 mm length along curve of carapace 80 mm thickness of carapace 25 mm

B Right Chela Chela preserved as internal mould with a few *fragments of armour in place incomplete robust and covered entirely* with fine granulations Roughly triangular in shape Proximal end contracted distal end broad Outside surface strongly convex inside slightly convex in central portion with a depression towards proximal end near outer margin Outer margin strongly curved towards narrow proximal end Inside margin nearly straight but tapering towards proximal end Both fixed finger and dactylus broken

Length of palm 50 mm width at proximal end circ 12 mm width at distal end 37 mm thickness of palm near distal end 27 mm

OBSERVATIONS This new species of crab from the Middle Miocene of Victoria closely resembles *Harpactocarcinus tumidus* described by Woodward from the Upper Oligocene of New Zealand (Woodward 1876) In *H victoriensis* the carapace is covered entirely with fine granulations, whereas in *H tumidus*, only the posterior part of the carapace is completely granulated the anterior portion being smooth There is also a difference in shape of the petalloid markings on the carapace of *H victoriensis* (only visible on paratype) and *H tumidus* The area between the tips of the two petals are broadly V shaped in the former and broadly U shaped in the latter The holotype of the Victorian species is slightly larger than the New Zealand form, and shows a greater depth when measured along the curve of the carapace The paratype exhibits less tumidity than either the holotype or the New Zealand species

Occurrence In brown fine grained, sandy and micaceous marls, Lakes Entrance Oil Shaft Gippsland Victoria, at the depth of 1,000 feet

Holotype Comm Pal Coll No F 15,644, Type No 318

Paratypes Carapace Comm Pal Coll No F 13,692, Type No 319 Chela Comm Pal Coll No F 15,645, Type No 320

Age Janjukian Stage of the Middle Miocene

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Explanation of Plate

Plate IV

Fig 1—*Herpactocarcinus victoriensis* sp nov Dorsal view of holotype,
Fig 2—Side view of same to show tumidity
Fig 3—Ventral view of same
Fig 4 *H victoriensis* sp nov Dorsal view of paratype
Fig 5—Ventral view of same
Fig 6—Inner view of right chela
Fig 7 Outer view of right chela

All figures are 2/3 of natural size

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4—A Critical Review of the Lower Palaeozoic Succession of Tasmania

By D. E. THOMAS

[Read 13th June, 1946]

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Abstract

The literature dealing with the Lower Palaeozoic rocks of Tasmania is reviewed and attention is drawn to the changing ideas of the correlation of these rocks and the reasons for these changes. It is pointed out that until detailed fossil collections are examined by modern palaeontological methods, the true sequences cannot be determined or the structural problems fully appreciated. It is suggested that the Cambrian follows the Proterozoic probably conformably, that the Ordovician is separated from the Cambrian by a diastrophic period and the same applies to the Silurian and Ordovician although in this case the age of the basal beds of the Silurian, the West Coast Range Conglomerates, has not been determined. There is a conformable passage to the Lower Devonian which corresponds to the Victorian Yeringian.

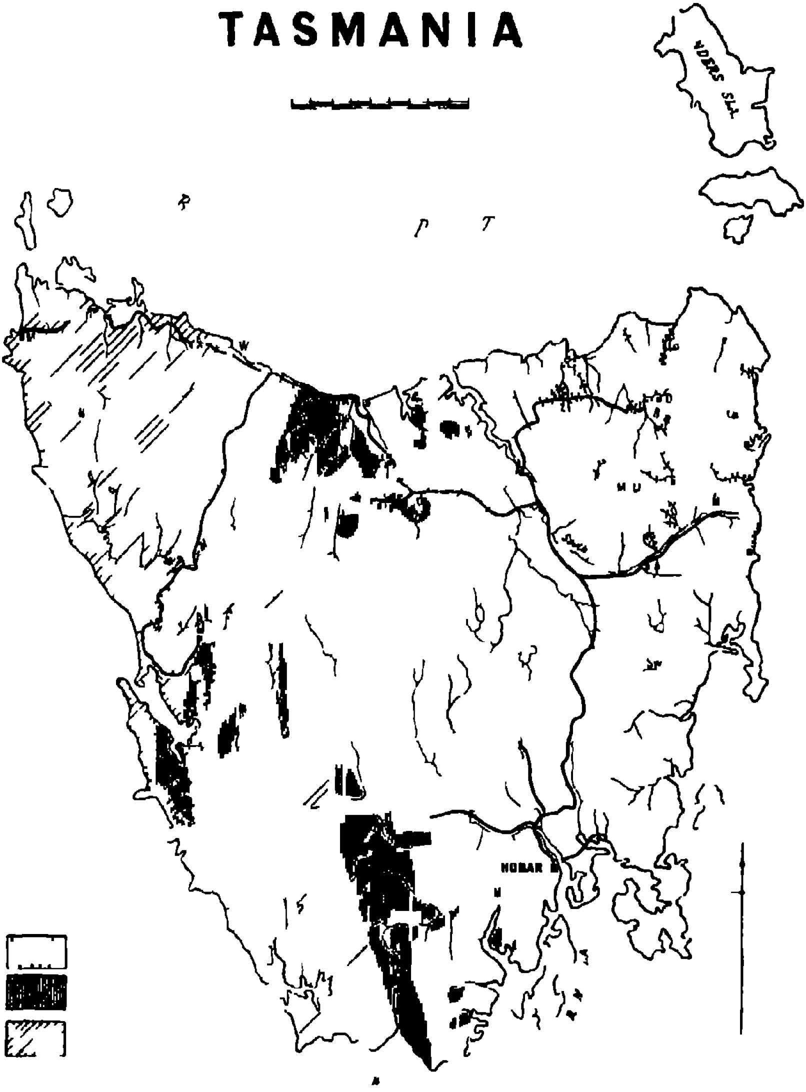
Introduction

During my short term as Government Geologist for Tasmania, much thought was devoted to the Lower Palaeozoic Succession as the metalliferous deposits are confined to these rocks. It soon became evident that the ideas as to the sequence had changed so often that the evidence that gave rise to these changes had to be assessed. It was intended to study some of these problems in the field, but owing to my return to Victoria this was not possible. These notes are intended as a summary of the scattered literature on this problem, to draw attention to some of the problems yet to be solved, to the need for fresh evidence and its study by modern palaeontological and stratigraphical methods.

Historical

Three main periods may be considered:

(i) *First Period from* 1860-1910. This embraces that period when field work was actively supported by identification of the fossils during these surveys. Thus Gould sent fossils to Salter and McCoy,



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CORRELATION TABLE

	Gould 1860-1870	R Etheridge & T Stevens 1882	Johnston 1888	Twelvetrees 1909	Twelvetrees & Ward 1910	P B Nye & A N Lewis 1928	Sir Edgeworth David 1932	Nye & Blake 1938	A N Lewis 1940	Dr D Hill 1942	Thomas 1946
DEVONIAN TO **SILURIAN** Upper Silurian of Early Authors	ELDON BEDS Caroline Ck Sandstones Don Chudleigh limestones Caroline Creek limestones Gordon River limestone West Coast Range conglomerates	North West Coast conglomerates	Fingal slates ELDON GROUP: Eldon Valley beds Dial Range and North West Coast conglomerates Queen River formation	Eldon Valley clay slates etc Fossiliferous limestones sandstones and slates at Zeehan, Heazlewood Queen and Nelson River etc	8 Pale slates & sandstones 7 Sandstones pebbly grits etc 6 limestone 5 Shale and slate	Middle Silurian Queen River slates & sandstones Gordon River limestones Tubicolar sandstones West Coast Range conglomerate series	Yeringian Zeehan sandstone etc Gordon River limestones Melbournian Despatch limestone Limestone of Lyell & Zeehan Tubicolar sandstone West Coast Range conglomerates etc	6 Queen River slate & sandstone series 5 Gordon River limestone series 4 Discoidal series 3 Quartzite series 2 Pipe stem or Tubicolar series 1 West Coast Range conglomerate series		Lower Devonian: Meurodictyum megastomum shales, Zeehan Point Hibbs limestone Ludlovian Wenlockian: Limestone on Gordon River Valentian: Limestone at Liena & Head of Nelson River	Eldon Group: Queen River series Mathinna slates (of North East) Gordon R Group: Gordon River limestones Tubicolar sandstone West Coast Range conglomerate series
ORDOVICIAN Lower Silurian of Early Authors			2 GORDON RIVER GROUP: Fossiliferous limestones slates grits & conglomerates at Point Hibbs Franklin River & Florentine Valley 1 AURIFEROUS SLATE GROUP: Auriferous felspar porphyries etc of Lymington slates of Beaconsfield Lefroy Mathinna etc	Slate and sandstone in goldfields of Lefroy Mathinna etc Limestones of Gordon, Florentine Railton Mole Ck Beaconsfield etc	4 ?Ordovician: Sandstones & slates of Wubeena Hills 3 Cambro Ordovician: Tuffs breccias spilitic, lavas etc	Diastrophic period Cambro-Ordovician a Porphyroid complex & Mathinna slates b Read Rosebery schists c Dundas slates d Mathinna slates e Balfour slates etc	Dundas series Limestones of Blenkhorns Quarry etc Cambro Ordovician: Dundas slates (possibly Middle Cambrian)	Diastrophic period Dundas slate series Cambro-Ordovician Balfour series (?Sil) Mathinna slates (?Sil) Rosebery series Sisters Hill series Farrell slates	JUNEE SERIES: 3 Junee limestone 2 Fossiliferous mudstones etc 1 Conglomerates breccias quartzites etc	Upper Ordovician or ?Silurian: Queenstown limestone Smelters Road limestone Note Arrows indicate possible range	Unconformity Diastrophic Period ? King River series Junee Series: Limestones (Junee, Melrose Railton Chudleigh etc ?Beaconsfield etc Caroline Creek sandstones 'Magog' conglomerates
CAMBRIAN		Caroline Creek Beds	3 PRIMORDIAL CALCIFEROUS GROUP: limestones of Chudleigh 2 MAGOG GROUP: Sandstones etc of Chudleigh Magog Range etc 1 DIKELOCEPHALUS GROUP: Caroline Creek grits etc	Incertae sedis: Dundas slates Lower slates Mt Lyell porphyries etc Dikelocephalus sandstones at Caroline Ck Discoidal sandstone Leddon River etc Tubicolar sandstone, Middlesex etc Conglomerates of West Coast Range	2 Tubicolar sandstone 1 West Coast Range conglomerate series	(a) Dikelocephalus sandstones of Caroline Creek (b) Dikelocephalus sandstones of Florentine (c) Slates of Hatfield Plains etc	Upper (Tremadocian) Caroline Creek series	4 Caroline Creek sandstone series 3 Florentine Valley slate series 2 Hatfield Plains series 1 Arthur River slate series	Unconformity Dundas series		Unconformity Dundas Series: Including ?Bischoff Balfour slates Rosebery Series Farrell slates Arthur River and Hatfield Plains Grey green quartzite ?stage White quartzite stage of Mt Ulter

BLE

Sir Edgeworth David 1932	Nye & Blake 1938	A N Lewis 1940	Dr D Hill 1942	Thoma 1946
Melbournian – Yeringian Zeehan sandstone etc Gordon River limestones Despatch limestone Limestone of Lyell & Zeehan Tubicolar sandstone West Coast Range conglomerates etc	6 Queen River slate & sandstone series 5 Gordon River limestone series 4 Crinoidal series 3 Quartzite series 2 Pipe stem or Tubicolar series 1 West Coast Range conglomerate series		Lower Devonian — Pleurodictyum megastomum shales Zeehan Point Hibbs limestone Ludlovian Wenlockian — Limestone on Gordon River Valentian — Limestone at Liena & Head of Nelson River	Eldon Group { Queen River series Gordon R Group { Gordon River limestones Tubicolar sandstone West Coast Ra conglomerat series
				Unconformi
Dundas series Limestones of Blenkhorns Quarry etc Cambro Ordovician — Dundas slates (possibly Middle Cambrian)	Diastrophic period Cambro - Ordovician Dundas slate series Balfour series (?Sil) Mathinna slates (?Sil) Rosebery series Sisters Hill series Farrell slates	JUNEE SERIES { 3 Junee limestone 2 Fossiliferous mudstones etc 1 Conglomerates breccias quartzites etc	Upper Ordovician or Silurian — Queenstown limestone or Smelters Road limestone Note Arrows indicate possible range	Diastrophic ? King River Junee Series { Limestones (Caroline sandsto Magu conglom
				Unconfor
Upper (Tremadocian) Caroline Creek series	4 Caroline Creek sandstone series 3 Florentine Valley slate series 2 Hatfield Plains series 1 Arthur River slate series	Unconformity Dundas series		Dundas Series Including { ?B schoff Roseber Farrell Arthur Hatfield Grey gre ?stage White quar

Johnston identified many himself and Stevens sent his to R. Etheridge, jun. Twelvetrees and Ward sent their fossils to be identified first by R. Etheridge, jun., and then by W. S. Dun, but after 1910 the fossils lists are for the most part merely repetitions of these earlier ones.

(ii) *Second Period,* 1910-1930. Very little systematics on fossils was carried out during this period, due to the unfossiliferous nature of much of the country examined, and to a concentration on mining properties to the exclusion of stratigraphical problems. During this period only occasional papers dealing with palaeontology appeared, and these were mainly by F. Chapman dealing with isolated occurrences.

(iii) *Third Period,* 1930 *onwards.* The date of the commencement of this period can be regarded as only approximate The events that initiated it may be taken as the realisation that the porphyroids were probably post-Silurian, due to the work of P. B. Nye, K. J Finucane, F. Blake, and Q. J. Henderson (mostly unpublished); to the description of fossil plants by Dr. I. Cookson and the redescription of some Ordovician fossils from published accounts by T. Kobayashi. This was advanced further by the field work of A. N. Lewis, in the Junee area, when he sent fossils from this district as well as some from Caroline Creek to Kobayashi. Then came the work on the corals by Dr. D. Hill and the discovery of "dendroids" in Dundas Slates.

FIRST PERIOD, 1860-1910

CHARLES GOULD: The first geologist to unfold, in any systematic manner, the structure of the lower palaeozoic rocks in Tasmania was Charles Gould, Government Geologist 1860-1870. In an exploratory journey which must rank high in the history of Tasmanian development, Gould in 1860-1862 mapped the country between Lake St. Clair and Macquarie Harbour, and thence northward across the Eldon Range and the Murchison to the Van-Diemen's Land Company's holdings in the north. In his reports of these journeys Gould records the main outlines of the lower palaeozoic formations developed in Tasmania and the most characteristic fossils of the more important members.

In 1860 Gould recorded a group of fossils from the western half of the Eldon Range to the Collingwood River, which shows that in this area is a group of rocks identical with those now called the Queen River Slate and Sandstone series and the Gordon River Limestone series. Among the fossils he identifies Calymene, Orthis and Cardiola. Calymene from Tasmania has not been figured so it is not possible to check this identification.

In 1861 Gould reported on the Mersey Coalfield and records the discovery of a fragment of a small trilobite at Caroline Creek. The beds in which this was found (termed by him ferruginous sandstones) were recognised to be in close stratigraphical association with the limestones of the Don Valley (Melrose) which he placed immediately below the Caroline Creek sandstones, the latter being succeeded upwards by conglomerates. In the footnote obviously added to this report after his visit to the West Coast, Gould laid the foundation of an error which led to subsequent confusion He states that after his work in the Mersey Valley he regarded the Don limestones as low in the palaeozoic succession but after a visit to the Great Bend of the Gordon and the Florentine Valley he considered the limestones occurring there is identical with those of the Don Valley (in this he was quite correct) but as the fossil evidence yielded by the limestones at the mouth of the Gordon (Macquarie Harbour) which he regarded as identical with those at the Great Bend (this in error) showed the Macquarie Harbour occurrence to be high in the Silurian he elevated the Don Chudleigh limestones to that position (Gould 1861)

In 1862 Gould published a report on Macquarie Harbour stated to be of a general nature only He took the beds of limestone as a key and enunciated the theory that Western Tasmania showed a series of parallel north south folds producing a repetition of beds from east to west

A considerable list of fossils is given These were taken from a collection made earlier by Dr Milligan (see Johnston 1888 p 62), supplemented by those gathered by Gould from the two beds of limestone—one near the mouth of the Gordon the other at the junction of the Gordon and Franklin Rivers extending several miles thence up both valleys (See map accompanying the report) Gould stated that he considered these limestones were identical with those at the Great Bend but did not advance any arguments in support of this view He considered the limestone to be underlain by sandstones and grits and below these occurred a bed of conglomerates (clearly from his descriptions what we know now as the West Coast Range Conglomerates) He placed the Eldon Valley mudstones as higher than the limestones and records that some similar rock outcrops at the mouth of the Gordon (It may be stated here for the sake of clarity that the Eldon Valley Series of Gould is what is now known as the Queen River Slate and Sandstone Series his limestone at the mouth of the Gordon is the Gordon River Limestone Series the underlying grits and sandstones are the Quartzite Series and the conglomerates the West Coast Range Conglomerate Series) So Gould had as early as 1862 a clear view of what may be termed the Silurian succession His correlation of these beds with the Don Chudleigh limestones and the associated Caroline Creek Series was followed by some subsequent workers and this has led to some confusion as the latter have since been shown by fossil evidence to be basal Ordovician

Gould s final contribution was in 1866 when he recorded the fossils which he stated had been identified by Professor McCoy Unfortunately complete lists were not given and Johnston (1888 p 62) stated that he failed to locate these lists elsewhere in any of our local records Gould s list includes the following

Orthoceratites
Lituites
Halysites
Favosites
Raphistoma
Orthis

Rhynchonella
Euomphalus
Murchisonia

Other collections had been submitted by Gould to Professor W. J. Salter and 21 species were given manuscript names. These were included in Bigsby's "Thesaurus Siluricus" and in the Catalogue of Australian Fossils by R. Etheridge (1881). They were also listed by Johnston, who states (1888, p. 62) "we are unable to determine to what extent the species still preserved in the Tasmanian Museum are included in the list. . . . "

T. STEPHENS AND R. ETHERIDGE, JUN.

T. Stephens (1874) investigated the Caroline Creek district and made a collection which was subsequently described by R. Etheridge, jun. (Stephens 1882). At the same time Stephens forwarded to Etheridge a small collection of fossils from the Table Cape Conglomerates, and these were described in the same report. This paper by Etheridge (1882) contains the original descriptions of many Tasmanian lower Palaeozoic fossils.

It should be noted that Silurian then included the Ordovician and Silurian of modern usage. Although Lapworth proposed the term Ordovician in 1879, as a compromise between the views of Murchison and Sedgwick, the absence of the term Ordovician, except in the table in Johnston's Geology (1888) indicated that the division was not recognised in Tasmania at that time. The fossils described by Etheridge fall into two distinct groups—(a) from Caroline Creek and (b) from Table Cape. It is now known that the Table Cape Conglomerates are of glacial origin and Permian age, so the discovery of fossils in included pebbles is of no great assistance in unravelling Tasmanian stratigraphy.

The following are the determinations:—

GROUP (a).
Conocephalites ? Stephensi
Dikelocephalus tasmanicus
Asaphus (two species)
Ptychoparia? (three species)
Ophileta?
(For a revision of the above see Kobayashi, 1936)

GROUP (b).
Pentamerus Tasmaniensis (Eth fil.).
Various *Spirifers*
Strophomena.
Tentaculites.

These latter determinations indicate that these pebbles are derived from beds in Gould's "Eldon Group" Etheridge assigned an Upper Cambrian age to Group (a) and Upper Silurian age to Group (b).

R. M. JOHNSTON.

The next writer was R. M. Johnston, in the Systematic Geology of Tasmania published in 1888. There we find for the first time in Tasmanian geological literature a comprehensive account of the lower palaeozoic rocks. In 1885 Johnston published a short paper which, however, has been largely incorporated into his Geology. He mentions the fact that Gould's specimens were identified by McCoy (a fact indicated by Gould but without reference to McCoy's actual report on the specimens), and that Gould regarded these Gordon River limestones as at 'the very base of the lower Silurian of Europe, interior to the described fossiliferous beds of Victoria as well as the Calymene containing beds of the Eldon Valley" The fossils show, however, that the beds are Silurian in age, and not at the base of the lower Silurian (=Ordovician of modern nomenclature) Johnston also mentions the earlier determination by Professor Salter in 1868 of 28 species These are all fossils typical of the Gordon River Limestone suite but the exact locality of the collection does not appear to have been recorded, and the list of Salter s description copied by Johnston in the paper under discussion is unaccompanied by illustrations Johnston gives figures of many of these genera in Plates IV, V, and VII of his Geology, but as he does not credit Salter with any of the types there illustrated it appears as if he figured other specimens for this work

The fossils described by Salter as Straparollus and figured by Johnston (Geology Plate V) are more typical of the Junee suite (to be described later), but the others are typical Gordon River forms Salter s collection may thus have come from more than one locality

TABLE 1—SUMMARISING JOHNSTON'S IDEAS AS TO THE GEOLOGICAL SUCCESSION

UPPER SILURIAN (=Silurian of modern usage)	ELDON GROUP	Tingal Slates Eldon Valley Clay Slates and Mudstones Dial Range and N W Coast Conglomerates Queen River Formation
LOWER SILURIAN (i e Ordovician of modern usage)	2 Gordon River Group	Fossiliferous limestones slates grits conglomerates and quartzose sandstones at Point Hibbs Franklin River Florentine Valley
	1 Auriferous Slate Group	Auriferous felspar porphyries Lymington Auriferous slates etc Beaconsfield Lefroy the Don Waterhouse Denison Back Creek Gladstone Mathinna, Mangana Mount Victoria.
CAMBRIAN	3 Primordial Calciferous Group 2 Magog Group 1 Dikelocephalus Group	Limestones of Chudleigh Belvoir Ilfracombe etc Sandstones and alum schists of Chudleigh (Magog Range etc) Caroline Creek grits and sandstones

The palaeontological evidence given by Johnston is summarised below —

CAMBRIAN

Dikelocephalus Group (The fauna of this group has been reviewed in detail by Kobayashi and no useful purpose will be served by listing the old names)

Magog Group No fossils were found, but he maintained the rocks were closely related to the Dikelocephalus Group" and may yet prove to be the same

Primordial Calciferous Group These rocks had yielded no fossils and he expressed doubt as to the position of these Cambrian rocks He considered that at Don Chudleigh and Magog Mountain the sandstones and limestones are closely in association with the Dikelocephalus bearing Caroline Creek Group He notes that Gould started with this idea but later correlated these limestones with the Gordon River limestones Johnston reverts to Gould s original idea

LOWER SILURIAN (ORDOVICIAN)

Auriferous Slate Group He mentions the Beaconsfield slates and grits with Licrophycus and at Lisle *Diplograptus nodosus* (not now accepted) and a bed replete with orthis

Gordon River Group Johnston s remarks (1888 pp 61 63) are a repetition of his 1885 paper and he adds nothing to the observations of Gould McCoy Salter and Etheridge there recorded

UPPER SILURIAN

Eldon Group—Queen River Formation

Johnston identified
Spirifera crispa (Hesinger) (sic)
S plicatella (Linn)
Orthis flabellum
O elegantula

DIAL RANGE AND NORTH WEST COAST CONGLOMERATE

He points out that the fossils in these were derived from the Queen River formation It is now considered that the Dial Range is capped by the West Coast Range Conglomerate while the north west Coast Conglomerates are of glacial origin and Permian age

ELDON VALLEY CLAY SLATES AND MUDSTONES

Johnston merely repeats Gould s observations of Calymene Orthis and Cardiola etc

FINGAL SLATES

The only fossil mentioned is a species of *Inodonta* closely resembling *A Jukesii* found in the Devonian rocks of Ireland (p 67) (In his comparative table (p 78) he also includes these beds in the Upper Devonian and mentions the soft slates Fingal with *Inodonta Gouldii* and undetermined plant impressions and refers doubtfully to the Devonian age of the Eldon Valley mudstones The high position of the Eldon Group and the Fingal Slates appears to be supported by additional information obtained in recent years)

Johnston figured many of these fossils which may be assigned to horizons in Nye and Blake s 1938 classification as follows —

Plate I Caroline Creek Series
Plate IV Gordon River Limestone Series
Plate V Gordon River Limestone and Queen River Slates and Sandstone Series
Plates VI and VII Queen River Slates and Sandstone Series and Discoidal Series

R MONTGOMERY AND R ETHERIDGE, JUN

The next important contribution to the unravelling of the Cambro Silurian succession in Tasmania was made in 1896 again by R Etheridge jun R Montgomery then Government Geologist, collected a suite of fossils from Zeehan and Heazlewood Etheridge described this comprehensive collection and very few collections of lower Palaeozoic shelly fossils have since been fully described from Tasmania

- TRILOBITA
  - *Asaphus*
  - *Hausmannia meridianus* Eth jun and Mit
  - *Amphion ? brevispinus* Eth jun
  - *Illaenus Johnstoni* Eth jun
    - From Despatch Limestone Zeehan
  - *Cromus Murchisoni* De Kon
    - From blue grey schistose rock Zeehan and from Heazlewood
- GASTEROPODA
  - *Murchisonia* D Arch and De Vern
  - *Lophospira* Whitfield
  - *Raphistoma* Hall
  - *Eunema Montgomerie* Eth jun
- BRACHIOPODA
  - *Rhynchonella decemplicata* Sowerby
  - *R cuneata* Dalman
  - *R capax* var *meridionalis* Eth jun
  - *R borealis* Schlotheim
  - *Strophomena* sp Rafinesque
  - *Stropheodonta* sp Hall
- PTEROPODA
  - *Tentaculites* Schlotheim
- CORALS
  - *Favosites grandipora* Eth jun
  - *Pleurodictyum?* Goldfuss
- VERMES
  - *Cornulites Tasmanicus* Eth jun

These fossils are typical of the rocks above the West Coast Range Conglomerate Series

R ETHERIDGE AND T STEVENS

The next advance was a description by Robert Etheridge of a new find of trilobites by Thomas Stevens from Florentine Valley (Etheridge jun 1904)

He described a new species of trilobite *Dikelocephalus florentinensis* Eth jun (now *Asaphopsis florentinensis* (Eth) see Kobayashi 1936) and recorded the form now known as *Tasmanocephalus Stephensi* Etheridge He also figured specimens of *Orthis lenticularis* Wahlenberg which is typical of these beds These descriptions establish the close similarity between the Florentine Valley series and the Caroline Creek series

W H TWELVETREES AND L K WARD

In 1900 1901 W H Twelvetrees contributed a valuable summary of our knowledge of Tasmanian Geology the first since Johnston s Geology had appeared in the Outlines of the Geology of Tasmania In this work he placed the Caroline Creek sandstones as Cambrian and grouped all the other known lower palaeozoic rocks as Silurian At the base of this group he placed the Gordon River Limestones which he grouped with the Railton Chudleigh Limestones etc and the Beaconsfield Lefroy Mathinna slates and sandstones All these he termed Lower Silurian The balance were placed in the upper and middle Silurian and included the Lyell schists conglomerates, etc Dundas and Mt Read slates etc brachiopod sandstones of Middlesex Heazlewood Queen River and Zeehan in that order

In 1907 1908 Twelvetrees and Ward inspected a section of country over which the Great Western Railway Company was asking for concessions This extended from Glenora to the Serpentine and via King William Range to Linda thus giving an east west section across the country occupied by lower palaeozoic rocks This section which included the trilobite beds of the Florentine valley will be dealt with later Their observations however remain as the only detailed report on much of the country covered (Twelvetrees 1908)

In 1909 Twelvetrees contributed observations on the mining fields of the north west dealing with the older rocks of the Lower Palaeozoic succession and in 1910 in collaboration with Ward with the younger rocks of this succession in the Zeehan area

His 1909 paper was written after his discovery of the trilobites described by Etheridge (1904) who had referred them to the Upper Cambrian He discussed the relationship between the Caroline Creek and Railton limestones regarding the Caroline Creek sandstones at Blenkhorn s quarry Railton as passing apparently conformably below the Lower Silurian limestone (Gordon River Series) He recorded a trilobite fragment from the quarry and *Raphistoma* from Railton township

At Gunn s Plains he described the limestone as resting on a series of cherty conglomerates breccias tuffs and chocolate coloured slates and described a conglomerate series from the Leven Gorge which he differentiated from the West Coast Range Conglomerate Series

He correlated the Leven series with the conglomerates outcropping at Penguin and he considered the conglomerates of Stowport and Blythe iron mines to be part of the same group He also correlated the Gunn s plains limestone with that at Mole Creek and assigned them both to the Gordon River Series He recorded the occurrence of *Actinoceras* in the Railton limestones which he correlated with the Gordon River Series on Gould s palaeontological observations but agreed with Gould that it is at the very base of the Lower Silurian (i e, Ordovician) A useful comparative table of succession is given on page 35, and this appears substantially upheld by observations to the present date with the exception of the correlation of these limestones with the Gordon River Series

Twelvetrees from time to time published most useful summaries of the stratigraphical Geology of Tasmania bringing his ideas on the succession up to date The last of these was published in 1909 and was generally accepted until the publication of a summary by P B Nye and A N Lewis in 1928 In his 1909 Outlines (p 122) Twelvetrees stresses with full reasons his view that the West Coast Range Conglomerate Series lies well below the Caroline Creek series and assigns a position low in the Cambrian for this He recognises that the West Coast Range Conglomerate Series is succeeded first by the Tubicolar Sandstones and that rock by the Discoidal Sandstone The Dundas and Leven slates and breccias or the considerable beds round Tim Shea and Mt Mueller towards the south-east are among his "incertae sedis" Twelvetrees gave an Ordovician age to the Gordon River limestones (based on observations at Railton) and classified all the major beds of lower palaeozoic limestones as of this series Succeeding this he placed the Fingal Mathinna Warrentina suite of rocks, also assigning them an Ordovician age He assigned a Middle Silurian age for the Eldon Valley-Queen River-Zeehan-Heazlewood limestones and sandstones from which fossils had been obtained, but recorded little in the way of data bearing on the succession of different stages or rocks of different localities in this group

SILURIAN
  Eldon Valley Clay Slates
  Fossiliferous limestone, sandstone and slate at Zeehan Heazlewood, Queen and Nelson River, etc
ORDOVICIAN
  Slate and Sandstone in the Goldfields of Lefroy, Mt Victoria Mathinna, Mangana
  Limestone on the Gordon, Florentine etc, at Railton, Mole Creek, Beaconsfield etc
CAMBRIAN
  Incertae sedis
    Dundas slates and breccias the Dial Range and Leven slates, etc the felspathic porphyries of Mt Lyell etc
    Slates and sandstone at the Needles and near Mts Mueller and Wedge
  Dikelocephalus sandstone at Caroline Creek etc
  Discoidal sandstone, Loddon River and Caroline Creek
  Tubicolar sandstone at Middlesex Five Mile, etc
  Conglomerates of the West Coast Range the Thumbs
PRE CAMBRIAN
  Amphibolites and quartzitic schists etc

In 1910 a revision of the rocks around Zeehan was made by Twelvetrees and Ward Their succession is as follows —

SILURIAN
  8 Pale and dark coloured slates and sandstones
  7 Sandstones pebbly grit, and greenish grey slate
  6 Limestone
  5 Shale and slate
UNDETERMINED (ORDOVICIAN?)
  4 Sandstones and slate of the Nubeena and Queen Hills
CAMBRO-ORDOVICIAN
  3 Tuffs breccias spilitic lava flows slates and sandstones
CAMBRIAN
  2 Tubicolar sandstone
  1 West Coast Range Conglomerate series

The low horizon of the Conglomerate series was based on the assumption that they were identical with the Denison Range Thumbs rocks (i e, outcrops near the Great Bend) Their position inferior to the Dundas Slates is also not acceptable to later workers

Their lists of Silurian fossils are interesting and are given below

Those from the limestones and determined, for the most part at least, by R Etheridge, jun, are —

TRILOBITA
Asaphus sp ind Despatch Limestone
Hausmannia meridianus (Eth & Mit) Despatch Limestone
Illaenus Johnstoni (Eth) Despatch Limestone
Amphion (?) *brevispinus* (Eth) Despatch Limestone

CEPHALOPODA
Orthoceras sp Despatch Limestone

GASTEROPODA
Trochonema (*Eunema*) *montgomerii* Despatch and Smelters
Raphistoma spp Smelters
Hormotoma sp Smelters

PELYCYPODA
Leptodomus (?) *muciformis* (Eth) Despatch
Palaeoneilo sp Smelters

BRACHIOPODA
Rhynchonella borealis var nov Smelters

VERMES
Cornulites Smelters

COELENTERATA
Favosites (?) Smelters

The list by W S Dun, from the overlying beds, is larger —

TRILOBITA
Calymene (close to if not identical with *C blumenbachii* (Brong))
Cromus murchisoni (de Kon) Mit
Hausmannia meridionalis (Eth & Mit)

CEPHALOPODA
Orthoceras sp
Actinoceras sp

PTEROPODA
Tentaculites sp

GASTROPODA
Murchisonia
Raphistoma sp
Lophospira spp

PELYCYPODA
Tellinomya jonesi (Johnston)

BRACHIOPODA
Strophomena sp
Dalmanella sp
One of the Meristidae
Camarotoechia sp
Pentamerus tasmaniensis (Johnston)
Spirifera of the *S sulcata* group
Spirifera of the *S cristata* group
Strophodonta sp
Trematospira tasmaniensis sp nov
Rhynchonella borealis var nov
Retzia (?)

VERMES
Cornulites tasmanicus (R Eth)
Annelida (?) (Pipestems)

CRINOIDEA
Crinoid ossicles stems etc

COELENTERATA
Zaphrentoid or Cyathophylloid (casts)
Halysites (casts)
Favosites (casts)
Pleurodictyum

He gave the range of the various forms and concluded they indicated a Silurian age though most probably low for the Zeehan rocks

These lists are important as very little palaeontological work has been carried out on these shelly faunas since this date so that they form the basis of the faunal lists which have been quoted later It is very unfortunate that many of these forms have not been described or figured and all will need revision on modern palaeontological lines The general similarity to the Yeringian of Victoria is very noticeable so that the beds are higher in the sequence than generally accepted

SECOND PERIOD 1910 1930

In the earlier period stratigraphical and palaeontological investigation went hand in hand The results of the studies of the mining fields appear for the most part in the Bulletins of the Geological Survey which commence in the year 1907 In the earliest of these attention is paid to palaeontological identifications but after 1910 attention was concentrated on mining problems rather than stratigraphic ones It is not intended to refer to all these reports but only to those that first advance new ideas

I K Ward in 1911 contributed a description of another group of lower palaeozoic rocks which he called The Balfour Slates and Sandstones and to which he assigned a Cambro Ordovician age based on the fact that they are penetrated by basic dykes (at that time provisionally considered to be Cambro Ordovician) Associated with the Balfour Slates and Sandstone series are conglomerates and some limestone both of unidentified age

The next important contribution was made by Loftus Hills in 1914 Hills working in the Jukes Darwin Range subdivided the West Coast Range Conglomerate Series into a lower brecciated conglomerate and an upper or normal conglomerate He considered that the lower brecciated conglomerate contained fragments of the porphyroid igneous suite at that time thought to be Cambro Ordovician and considered that the breccia conglomerates rested unconformably on the upturned edges of the porphyroids He regarded the two stages of the series as conformable and recorded Silurian sediments identified by their fossil contents on both sides of the Range (as is the case further north) He then (p 59) advanced reasons for placing the whole West Coast Range Conglomerate Series between the porphyroids and the Gordon River Limestone Series discussing and rejecting a number of other possibilities Hills then gave a pre Silurian age to the West Coast Range Conglomerate Series the deposition of which was preceded by a major period of diastrophism Similar features and relationship of the West Coast Conglomerate Series at Mt Murchison were later recorded by the same writer (Hills 1915)

The Dundas Slate Series was described by Hartwell Conder (1918) who regarded them as Cambro Ordovician on the slender evidence of the graptolite thecae (recorded by T S Hall in 1902) found in rocks of this series on the North West Dundas tram line

The Dundas Slates and West Coast Range Conglomerate Series as developed in the north west (south and west of Sheffield and Wilmot) were described by MacIntosh Reid (1919) who established an unconformity here between the Dundas Slates and the West Coast Range Conglomerate Series and indicated that the latter are subsequent to the porphyroid group of igneous rocks Some Silurian trilobites *Rhynchonella* and *Orthis* were identified from clayey sandstone associated with limestones at Bell Mount indicating an age later than the Tubicolar Sandstones

In 1919 F Chapman described a new coral *Tetradium tasmaniense* Chapman from the Limestone on Smelters Road Zeehan This is the Despatch limestone of Montgomery and Etheridge Chapman assigns an upper Ordovician or basal Silurian age for this fossil and it is also interesting to note that he calls this Zeehan limestone Gordon River limestone

The next general summary was published by Loftus Hills in 1921 Except for a few paragraphs on the position of the West Coast Range Conglomerate series this summary adds nothing material to the accounts above abstracted

P B Nye (1923) described the Dundas Series and the Bischoff Slate and Sandstone series (correlated with the Balfour Series) as occurring round Mt Bischoff Both Nye and Hills throw grave doubt on the age determination of the Dundas Series as based on Hall s graptolites but indicate that it lies quite definitely between the schists assigned to a pre Cambrian age and the West Coast Range Conglomerate Series assigned to a Silurian age with marked unconformities marking both extremities Nye places the Bischoff Series as younger than the Dundas Series and assigns to it an Ordovician age Silurian strata similar to those at Zeehan etc with fossils typical of these rocks as developed elsewhere are also recorded

This account was supplemented and confirmed by McIntosh Reid in 1923 who gives a further account of the Dundas Slates and Bischoff series The latter are stated to be separated from the former (earlier) series by an unconformity

The extensive tract of old rocks in the south west of the State was also not neglected McIntosh Reid described these near Adamsfield (Reid 1921) and in 1923 A N Lewis described the country around Mt Anne Neither author described fossils by which the age of the rocks could be determined

In 1924 appeared the next contribution of major importance to the unravelling of the Cambro Silurian succession problem This was a tentative opinion by McIntosh Reid that perhaps the Railton Don limestones were not properly assigned to the Silurian Gordon River Limestone Series reverting to Gould s first opinion and Johnston s view In this he was not influenced by the discovery of fossils but of a dyke belonging to the porphyroid series which cut limestones near the Paloona Pumping Station At this time these igneous rocks were supposed to be older than the West Coast Range conglomerates As they intrude the limestones here these must be older than the typical Gordon River limestones which overlie the Conglomerates He discussed the age of the limestones at some length (pp 22 26) and advanced the opinion that they are of Ordovician age thus separating them from those near Zeehan He also correlated the conglomerates of the Mersey valley with the West Coast Range Con glomerates (thus differing from the views expressed by Twelvetrees 1909) although he was correct in comparing them with Johnston s Magog Series

In 1925 Reid identified the Bischoff Series in the Dundas district but now advanced the view that it was older than the Dundas Slates, thus reversing the succession as propounded by Nye

In 1925 F Chapman described (?) *Hurdia davidi* found by Sir Edgeworth David on the Emu Bay Railway four miles south of Hatfield Plains On this slender evidence he assigns to these rocks a Middle Cambrian age

In 1928 he described some well preserved annelid trails as a new genus and species *Tasmanadia twelvetreesi* to which he gave a Cambrian age

In 1928 there appeared a general summary of Tasmanian Geology by P B Nye and A N Lewis This gives the views then generally held as to the succession which is summarised in the following table —

MIDDLE SILURIAN
  Queen River Slates and Sandstones
    At Zeehan valley of Queen River Heazlewood and Middlesex Plains
  Gordon River Limestones
    Lower Gordon River Chudleigh Mole Creek Ulverstone Railton Florentine River Junee and Ida Bay
  Tubicolar Sandstone or Quartzite Series
    Lies between the overlying limestones and underlying sandstones
  West Coast Range Conglomerate Series
    These form the base of the Silurian Rocks

CAMBRO ORDOVICIAN
  Diastrophic Period
    (a) Porphyroid igneous complex
    (b) Read Rosebery schists
    (c) Dundas Slates
    (d) Mathinna slates and sandstones
    (e) Balfour slates and sandstones

CAMBRIAN
    (a) Dikelocephalus sandstones of Caroline Creek
    (b) Dikelocephalus sandstones of the Florentine Valley
    (c) Slates of Hatfield Plains

Nye and Lewis present several lists of fossils (unfortunately with some typographical errors) As the exact localities are not given and as many of the forms have not been illustrated it is difficult to comment on these lists Some of the forms however e g *Pleurodictyum* would indicate a higher horizon than the authors would give their Silurian beds which thus may extend into the Lower Devonian and would be comparable with the Yeringian of Victoria

No fossils are recorded from the Tubicolar Sandstone or the underlying Conglomerates

It is pointed out that several groups of rocks included in the Cambro Ordovician have yielded no fossils and so cannot be correlated with each other The limestones at Railton however are correlated with the Larapintine as they contain *Actinoceras* cf *tatei* and *Trochoceras*

No new records for the Cambrian are given but they state that Dr F Whitehouse was examining the fossils and had suggested that *Tsinania* was present

P B Nye published a most important contribution to the Palaeozoic problem in 1929, when describing Adamsfield Prior to this account with the exception of the brief references by Twelvetrees in 1908, no important discoveries of the Silurian series, other than some doubtful references to the West Coast Range Conglomerate Series along the North-West Coast had been made east of the great pre Cambrian axis which runs northwards from Port Davey past Frenchman's Cap to Cradle Mountain Nye considered that considerable occurrences of the Gordon River Queen River Series occur at Adamsfield

The basis of Nye's correlation is the identity of the conglomerates of the Thumbs Saw Back Range, with a second parallel ridge to the west These he assigns to the West Coast Conglomerate Series Doubt was cast on this correlation by Lewis (1940), and fossil evidence obtained at Adamsfield by Thomas (1943) showed that the limestones were basal Ordovician in age They are thus the repetition to the west of the Junee and Florentine beds with their *Tasmanocephalus* fauna

It should be noted that Nye's fossil collections from Adamsfield have not yet been described (Nye personal communication) a task which should shed much light on the Ordovician succession

Third Period 1930 Onwards

This period was initiated by the structural work of the Tasmanian Geological Survey in the north and west of the State and by the work of A N Lewis in the south The palaeontological work is by workers outside Tasmania and marks the beginning of modern palaeontological research in that State

1932 Sir T W Edgeworth David gave a useful summary of his ideas as to the sequence which is as follows —

Silurian
    Yeringian
        Zeehan sandstones
    Melbournian
        Gordon limestones
        Despatch limestones
        Limestone of Lyell and Zeehan
        Tubicolar sandstones
        West Coast Range Conglomerates

Ordovician
    Dundas Series with *Callograptus* sp
    Limestones of Blenkhorn's Quarry with large Cephalopods

Cambro Ordovician
    Dundas Slates with Hurlia (possibly Middle Cambrian)

Cambrian
    Upper (Tremadocian)
        Caroline Series with Asaphellus Tsinania Crepicephalus etc

K J Finucane (1932) distinguished a Rosebery or Pre Dundas Series, which underlies the Dundas Series and showed that the porphyries as well as some basic rocks were intrusive into the Lower Palaeozoic sediments

In 1934, in the Bulletin on the Smithton Area (Nye Finucane and Blake) a group of slates that was correlated with the Dundas Series was described Above this is the Dolomite, and beneath it the

Chert Stage. Beneath the latter is a considerable thickness of beds divided into —

2. Grey Green Quartzite Stage,
1. White Quartzite Stage.

No fossils were found, but the beds are considered to be conformable, although there may be an unconformity between the Quartzite Stages. The sequence is interesting, as it shows for the first time a downward succession to beds formerly correlated with the Proterozoic period.

In 1936 T. Kobayashi, in reviewing the fossils from the Mersey River district, proposed the new genus *Tasmanocephalus,* and maintained that the beds were Ordovician in age.

In the same year, Dr. I. Cookson described the fossil plants found by F. Blake at Warrentina, and compared them with *Hostimella* and *Hedeia,* and inferred that the beds were Upper Silurian or Devonian in age.

The most recent summary of Tasmanian Geology, and the most complete that has been published since Johnston's Geology, is that by Nye and Blake (Geological Survey Bulletin No. 44, 1938). They subdivide the Lower Palaeozoic rocks as follows:—

SILURIAN
VI Queen River Slate and Sandstone Series
V Gordon River Limestone Series
IV Discoidal Series
III Quartzite Series.
II Pipe Stem or Tubicolar Series
I West Coast Range Conglomerate Series

ORDOVICIAN.
Dundas Slate Series

CAMBRO-ORDOVICIAN.
Balfour Series Slates, Quartzites and Conglomerate (but ? Silurian)
Mathinna Slates and Sandstones (but ? Silurian)
Rosebery Series
Sisters Hill Series
Farrell Slates

CAMBRIAN
IV Caroline Creek Sandstone Series
III Florentine Valley Slate Series.
II Hatfield Plains Slate Series.
I Arthur River Slate Series.

They discuss the relationship of the various rock groups, bring the lists of fossils up to date and mention unpublished identifications by R. Etheridge and F. Chapman. From these lists (which unfortunately contain many typographical errors) it can be seen that descriptions of many of the genera and species have not been published for Tasmania. For full details, which will not be given here, the above publication should be consulted.

A. N. Lewis in 1940 described in some detail the geology of the Tyenna Valley. This is a contribution of great importance, as the collections he made were sent to T. Kobayashi, who described the fossils and established their Lower Ordovician age. They were also examined by Dr. Whitehouse, who also assigned them a low Ordovician age (p. 48). Lewis proposed the Junee Series for these rocks, and his sequence for these rocks is as follows;—

3. JUNEE SERIES.
    - iii Blue Junee Limestone.
    - ii Yellow mudstone containing trilobites and other fossils of Lower Ordovician age.
    - i Quartzites with conglomerates and breccias interbedded

2. PROBABLE UNCONFORMITY
1. GREY SLATES PROBABLY REFERABLE TO THE DUNDAS SERIES

He also cast doubt on Nye's age determinations at Adamsfield and suggested that the rocks there are part of the Junee Series.

1940. T. Kobayashi described collections sent him from Caroline Creek and Junee by A. N. Lewis. From Caroline Creek he listed two genera of brachopods, two of gastropods and five genera of trilobites—

Euomphalid
Cryptolites sp.
Tasmanocephalus stephensi (Etheridge)
Asaphus sp.
"*Asaphellus*" *lewisi* Kobayashi
Etheridgaspis carolinensis (Etheridge)
E johnstoni (Eth.)
Carolinites bulbosa (Kob)
C quadrata (Kob)
C (?) *tasmanicus* (Eth.).
Prosopiscus subquadrata (Kob)

From Junee he lists—

Orusia (?) sp.
Sinuopea (?) sp
Roubidouxia (?) sp
Lecanospira tasmanensis Kobayashi
Asaphopsis juneensis Kob
A (?) *gracicostatus* Kob.
Tasmanaspis lewisi Kob
T longus Kob

He concluded that the faunas of Caroline Creek, Junee and Tim Shea are all Lower Ordovician, with the Caroline Creek beds slightly the oldest (in his paper in the Japanese Journal of Geography and Geology, 1940).

In 1941, Hill and Edwards identified the following fossils from Queenstown—

Alveolites sp
Protarea cf. *richmondensis*
Acidolites sp.
Tetradium tasmaniense Chap
Acantholites sp

and suggested that the beds were Upper Ordovician or Lower Silurian. The fossils referred to above had been previously commented on by R. B. Withers (Edwards 1939).

In 1942, D. Hill described some Tasmanian Palaeozoic Corals, and in the following year repeated her views in her paper, "A Re-Interpretation of the Australian Palaeozoic Record, based on a Study of the Rugose Corals."

Her age determinations for Tasmania are briefly as follows:—

UPPER ORDOVICIAN OR ? SILURIAN.

Chudleigh Limestone, Liena, Mersey Valley, with *Favistella*, *crinoids* and *tabulate corals*,

Grey Limestone at head of Nelson River, with one tabulate form.
Old Queenstown Flux Quarry with *Tetradium*.
Limestone on Smelters Road, Zeehan, with *Tetradium*.

SILURIAN, UPPER WENLOCK AND POSSIBLY LOWER LUDLOW.

Limestone of the Gordon River with two species of *Rugosa*.

SILURIAN AND/OR DEVONIAN.

Point Hibbs, with *Heliophyllum ? chillagoense* and *Favosites* *? bryani*

LUDLOVIAN OR PROBABLY LOWER DEVONIAN.

Zeehan, with *Pleurodictyum megastomum*.

D. E. Thomas and Q. J. Henderson in 1945 described hydroids and dendroids and recorded fragments of trilobites from the Dundas slates. The following forms were identified:—

Archaeocryptolaria skeatsi Chapman.
Mastigograptus sp
Cactograptus flexispinosus Chapman and Thomas.
Protohalecium hallianum C and T.
Sphenoecium filicoides (Chap.)
Sphenoecium sp.
? Protistograptus

From the similarity of these forms to those found in Victoria in undoubted Middle Cambrian rocks the authors conclude that the Dundas Series must be of Cambrian age.

In the same year Thomas reviewed the evidence for the occurrence of graptolites in Tasmania, and came to the conclusion that none of the records can be substantiated, and that T. S. Hall's record from Dundas falls in line with the determinations of dendroids as listed above.

The Porphyroid Suite of Igneous Rocks

These are a suite of plutonic, hypabyssal and, according to some of the workers, even volcanic rocks. As a group they are important in the mining fields in the western part of the island. Many opinions as to the age of these rocks have been expressed, based mainly on their general relationship to the sedimentary rocks. L. Hills, in 1914, as a result of observations south of Linda, and a review of the ideas of earlier workers, stated that they had been consolidated, weathered and subjected to diastrophic movements prior to the deposition of the West Coast Range Conglomerate Series, and so were assigned an Ordovician age. Several other workers, assuming the Ordovician age as proved, have used this igneous suite as a basis for the correlation of some of the sedimentary series.

Work by K. J. Finucane in the Rosebery district (1932) and by P. B. Nye, F. Blake and Q. J. Henderson in the Lyell area is indicated in Bulletin No. 44, 1938, pp. 36, 41, 42. (Details of this are not published but are in the mss. reports by these authors.) They maintain that these igneous rocks are intrusive into the Silurian and that the schistosity was due to the same diastrophic movements that folded these older rocks (see also H. J. C. Conolly 1940, who holds similar views). Thus the schists of Lyell, the Queen River, and Read-Rosebery, the "porphyroid igneous complex" and the felsites and keratophyres so important in the mining fields and so fully discussed in many of the Survey Bulletins, become the minor intrusions associated with the granitic intrusions of post-Devonian times.

The evidence of contemporaneous volcanic activity in the Dundas Slates has never been doubted, and there is a possibility that this igneous activity has not been differentiated from the younger in all cases.

All the age correlations based on these igneous rocks should thus be considered very doubtful, and have not been considered in the present discussion.

Discussion of the Lower Palaeozoic Succession

THE UPPER BEDS

THE SILURIAN-DEVONIAN FOSSILIFEROUS BEDS.

A convenient starting point for a discussion on the lower palaeozoic Succession in Tasmania is the limestone in which Gould found his type fossils, and which is well developed round Macquarie Harbour and Zeehan. This is distinguishable by certain clearly recognisable fossils indicating an age either Silurian or early Devonian.

These fossils are found in great quantities in certain layers of blue limestone and white sandstone occurring principally to the west of the West Coast Range. The typical limestones are at the mouth of the Gordon and Franklin Rivers, and have been called the Gordon River Limestone Series, which is clearly identifiable from the fossil assemblage. From these localities on the Gordon, beds containing similar fossils and clearly referable to the same series occur, with some breaks, northward to Zeehan, and with some isolated occurrences at Heazlewood and Eldon Valley.

They are particularly well developed between Queenstown and Strahan (Queen River area) and at Zeehan. In the latter areas, beds of limestone are interbedded with thick sandstones, grading sometimes into quartzites, and with thinner beds of grey slate. In the Queenstown and Strahan areas they are intruded by basic and acid rocks, the "porphyroids," now themselves in places metamorphosed into schists.

At both Zeehan and Queenstown the limestone beds are interbedded with the sandstones, which in places are also very fossiliferous. It was from such beds that Montgomery and Twelvetrees collected the fossils already referred to (Etheridge 1896, Chapman 1919).

The succession is not known in detail, but it appears that the blue limestones are developed as lenses, and although the same general suite of fossils characterises these rocks, until detailed modern palaeontological research is carried out it is difficult to determine their exact horizons. This series includes Johnston's Lower Silurian and Upper Silurian (Johnston 1888, p. 54) subdivided by Twelvetrees into the Discoidal Series, the Gordon River Limestone Series and the Queen River Slate and Sandstone Series, and which are more fully described by later authors (Nye and Blake 1938). The Gordon River limestones are well developed in the localities on the Gordon, but at

Zeehan they appear to be lenses in the sandstone, slates and quartzites which may be the Queen River Slate and Sandstone Series.

It appears, therefore, that in some areas the series contains a very thick development of limestone, but in other areas the limestones are thin or absent. The whole series, thus, consists of rapid alternations of limestone, sandstones and slates.

The following, from the general similarities of their fossils, can be considered as belonging to one series:—Blue limestones of the lower Gordon Valley (Gould 1860, 1866) (but not those of the Great Bend of the Gordon); the rocks showing the fossil suite referred to, which lie between the Gordon River and Strahan and thence to Queenstown and the valley of the Queen River and extending west of the mountains (i.e., over the Henty peneplain) to Zeehan; the rocks at Zeehan (Etheridge 1896, Twelvetrees and Ward 1910, Chapman 1919); the rocks at Heazlewood (Etheridge 1896) and Middlesex (Reid 1919) and Gould's "Calymene" beds of the Eldon Valley.

West Coast Range Conglomerate Series.

These have been divided into three conformable lithological groups:

3. Tubicolar Sandstone.
2. Normal Conglomerate.
1. Lower Brecciated Conglomerate.

(Further subdivisions, however, have been proposed in unpublished work by Conolly, see Edwards 1943.)

Although forming an easily identifiable lithological group, the age determinations given this group have ranged from Lower Cambrian to Upper Silurian.

The type locality is that part of the West Coast Range from Mt. Murchison to Mt. Sorell. Here there appears to be little doubt as to the horizon and relationship of the series, but there is a possibility that beds of conglomerates of the same general appearance exist in many parts of the State at a different geological horizon, and confusion has arisen from this factor.

The assignment of the West Coast Conglomerate Series to a position unconformably overlying the rocks containing asaphid trilobites (Lower Ordovician) and conformably underlying the rocks containing phacopid trilobites (Silurian) is the most reasonable, and has been adopted by Nye and Blake (1938, p. 37), who stated that this series "unconformably overlies the Dundas and other Cambro-Ordovician series and underlies the fossiliferous Silurian rocks." This stratigraphical horizon was suggested by G. A. Waller in 1903 and definitely assigned to it by Loftus Hills in 1914.

Owing to the absence of fossils, the exact age of this group cannot be determined. If some of the limestones (D. Hill 1943) to the west of the West Coast Range, and if the King River Series (Nye, Blake and Henderson (manuscript report 1934) are Upper Ordovician, the age can be fixed within narrow limits, and can be considered broadly as Silurian.

The beds succeeding the conglomerates or into which they pass laterally are the Tubicolar Sandstones. Previous opinion assigns an annelid origin to the tubes that characterise these beds (Twelvetrees and Ward 1910, pp. 28-30), but these are of no aid in age determinations.

Reid (1919) records shelly fossils typical of the Gordon Zeehan rocks from beds at Bell Mount (in the Middlesex area) which succeed the Tubicolar Sandstone stage. No detailed account of the succession is given, and L. Hills (1914, p. 54) is equally indefinite in regard to the upward succession at Jukes-Darwin and Crotty. Twelvetrees and Ward have described the series occurring round Zeehan, but do not record any section which shows a continuous succession (Twelvetrees and Ward 1910, pp. 33-39). L. Hills (1921, p. 121) maintained that the Gordon-Zeehan series succeeded the Tubicolar sandstone conformably, and Nye and Blake (1938, p. 38) also hold this view.

Published records of the actual contact of the conglomerates with the underlying beds are few, but all observers agree that it is an unconformity.

L. Hills (1914) stated that these rocks rested unconformably on volcanic rocks which must have been extruded subsequently to the formation of the Dundas Slates. With the identification at Junee-The Needles-Tim Shea of beds of conglomerate not easily distinguishable from this series, but overlain by limestones and sandstones bearing asaphid trilobites of Lower Ordovician Age, and the removal of Hills' basis of classification by the discovery of a later age and intrusive nature for the igneous rocks, doubt arises as to whether all the conglomerates called the West Coast Range Conglomerates Series are correctly correlated.

Thus Twelvetrees considered that the conglomerate occurring on the Thumbs-Denison Range dipped under the limestone of the Florentine Valley. (Twelvetrees, 1908, vide Section 3-4.) As he considered that the limestone was of Ordovician age, he assigned a Cambrian age to the conglomerates. Later the Florentine limestone was identified with the Gordon River limestone series and the conglomerates with the West Coast Range conglomerate series (Twelvetrees and Ward 1910, pp. 33-34; Nye 1929, pp. 11-12).

A. N. Lewis (1938) expressed doubt that this wide correlation of the conglomerates at Adamsfield with the West Coast Range conglomerate was justified, and that the sequence at that place would be correlated with the Junee Series and the lower Conglomerate. This view has been proved correct by further work in this area (Thomas, Thomas and Henderson, 1945).

McIntosh Reid (1919) based his correlations of the conglomerate of Black Bluff, Mt. Rowland and the Middlesex area on the relationship of the igneous rocks as stated by L. Hills in the Jukes-Darwin area. Reid's description however indicates that the West Coast Range Conglomerate Series is present in the Sheffield-Middlesex area.

THE MATHINNA SLATES.

Some brief reference must be made to the rocks that outcrop around the Ben Lomond Plateau in the north-east of the State. These have usually been included in the Cambro-Ordovician, but have yielded very few fossils, and being to some extent isolated from the other rocks their stratigraphic correlation is in some measure of doubt.

A fairly well recognised and consistent series has been identified and named the Mathinna Slates (Twelvetrees 1911, 1916). Nye (1923) suggested a correlation with the Balfour and Bischoff Slates and Sandstones and an Ordovician age, but gave no fossil evidence. McIntosh Reid (1925) suggested a correlation with the Dundas Slates and a similar age.

The most recent contribution to the age of these rocks is that of Dr. I. Cookson (1936). In 1934, F. Blake found some fossil plants at Warrentina, and this discovery led to the paper by Dr. Cookson. She compares the forms with *Hostimella* and with *Hedeia*, both of which occur in Victoria in beds of Upper Silurian and Lower Devonian age.

Plant remains have also been found on the main road from Launceston to Scottsdale, near Springfield (Thomas 1943), thus indicating that beds high in the Silurian or of Lower Devonian age are widespread in N.E. Tasmania. There is a strong possibility that rocks of a similar age are to be found much further to the south in the Fingal area, as Johnston records (1888, p. 59) "*Anodonta Gouldii* and Undetermined Plant Impressions" which made him include these beds in the Upper Devonian. At the same time it should be noted that he also included the Fingal Slates in the Upper Silurian (idem. p. 67). "No fossils have as yet been discovered, if we may except certain slates which are supposed to succeed them, from which the writer obtained a single species of *Anodonta*, closely resembling *A. Jukesii*, found in the Devonian rocks of Ireland."

Whether rocks of the same age extend to Lisle is not known. Thureau's "*Diplograptus nodusus*" was not accepted by T. S. Hall (1902), but Johnston found a sandstone which was replete with casts of a small species of *Orthis*, together with crinoidal stems. Further collections are necessary before the horizon of these beds can be determined.

The rocks of Beaconsfield may not belong to this group, although it appears reasonable to correlate the west Tamar rocks with those of the Lisle, Lefroy and Warrentina to the east of the Tamar. On the other hand, there has always been an assumption that the Beaconsfield limestones were to be correlated with those of Chudleigh and Mole Creek.

According to Nye (1928) conglomerates rest unconformably at Frankford, on the western side of the Tamar River, on older schists. "The conglomerates pass upwards conformably to sandstones, slates and the limestone of the Flowery Gully district. This series, many thousands of feet in thickness, should underlie the Mathinna Series..." This may be the clue to the relationship of the Silurian to the Ordovician in this part of the State.

THE ORDOVICIAN ROCKS

The extensive and economically important beds of massive limestone which occur in the Don-Melrose-Railton area, at Marrawa and at Gunn's Plains, Mole Creek and Chudleigh; at the Florentine River, Junee and the Great Bend of the Gordon; at the Weld River and at Ida Bay and New River are here referred to the same general horizon.

The Railton Melrose area has been mapped by Reid (1924). In discussing the age of these beds (1924, pp. 25-26), he recorded Ordovician fossils in the limestone and Silurian in the sandstone, although these were supposed to be interbedded, and he placed the Caroline

Creek sandstones in the Cambrian and the Railton limestones as succeeding these and of Ordovician age. (The Caroline Creek sandstones are now referred to the Ordovician, Kobayashi 1936).

At Caroline Creek (Haine's brick works) the sandstones, which yield *Tasmanocephalus*, are faulted against Permian rocks to the eastward, but elsewhere are covered by Pleistocene gravels, so that their relationship with the limestone is not observable. At Railton the succession appears to be in ascending order, conglomerate, Caroline Creek sandstone, and limestone observable at Blenkhorn's Quarry. Twelvetrees records collecting "*Ptychoparia stephensi*" (now *Tasmanocephalus stephensi*) at Blenkhorn's Quarry, from sandstones passing conformably below the limestone (Twelvetrees 1909, p. 8). He also records yellowish slates and sandstones in the Railton township, in which impressions of *Raphistoma* were found. These sandstones underlie the limestone of the Goliath Cement Company quarry and the limestones outcrop again in the valley of the Don on the Melrose railway, half a mile north of the quarries.

A. N. Lewis (1940) described the Junee series and correlated this with the rocks at Railton and Melrose. He maintained that the two corresponded sufficiently closely to justify their being grouped as one series which he named the Junee series This extends to Tim Shea, where T. Stephens had discovered asaphid trilobites, and thence through to the Florentine and to the Great Bend of the Gordon. It also extends south of Mt. Mueller to the limestones at the head of the Weld. These limestones are interbedded with sandstones in which certain bands contain trilobites and other shelly fossils.

Limestones of the same age group include the beds at Gunn's Plains and Leven Valley (Twelvetrees 1909), and probably those under Quamby Bluff (Reid 1924).

On the information at present available it is impossible to definitely assign the beds at Mole Creek, Chudleigh, at Hastings, Ida Bay and at New River to this series, but in all probability they should be included in this group. The limestone at Beaconsfield (Ilfracombe) is still more difficult to place.

All these limestones are the "Primordial Calciferous Group" of R. M. Johnston (1888, p. 39-41). This group starts with conglomerates, which may be taken to mark the base of the Ordovician rocks. Both the conglomerates of this lower series and the West Coast Conglomerate Series were effected by the (?) epi-Devonian diastrophism, and the task of distinguishing between the influence of this younger and of the older one affecting only the lower groups has not yet been undertaken in the field.

Thick beds of quartzite and conglomerates are to be found everywhere that the Melrose-Junee series outcrops. Gould and Johnston recognised this conglomerate series in the Mersey Valley, and Johnston named it the "Magog Group," from the mountain of that name which is composed of this series. Later Twelvetrees identified the series on the Needles, and Lewis (1940) stated that it also caps Tim Shea, although Twelvetrees assigned the conglomerates there to a Permo-Carboniferous age. The conglomerates should thus on the grounds of priority in nomenclature be named the Magog Conglomerates.

Gould (1861) considered they succeeded the Melrose Limestone, and Johnston (1888 pp 38 39) held a similar view of their relationship to the limestone at Chudleigh Later investigations however, reversed this order of succession Thus Twelvetrees (1909 p 9) identified this group at Gunn s Plains and in the Leven River Valley He distinguished these conglomerates from the West Coast Range Conglomerates and he also included in his Magog Group the Conglomerate at Penguin (Neptune Mine) Stowport the Blythe Iron Mines and Emu River and lists sections where they pass under the succeeding limestone

McIntosh Reid (1924 p 27) however correlated with some doubt the Magog Conglomerates with the West Coast Range Conglomerates mainly on the identification of Rhynchonella in the overlying Tubicolar sandstones on the east of Badger Range and at Denny Gorge, Paloona Hill and Moina but differentiated a lower conglomerate at Bott Gorge Reid (1921 p 17) also calls attention to the possibility that conglomerates of this series in the valleys of the Gordon and Florentine rivers (i e Denison Range Thumbs Tim Shea Needles) have been confused with the West Coast Range Conglomerate Series He had investigated the latter area in the course of his work on Osmiridium in Tasmania and the view thus briefly expressed corresponds with that A N Lewis (1938) and of myself and Q J Henderson (1943)

It is probable that the conglomerates of the Magog Group vary rapidly both laterally and vertically into sandstones and quartzites Without fossil evidence it thus becomes very difficult to separate these beds from lithologically similar ones occurring above the West Coast Range Conglomerates

Along the North Coast particularly at Ulverstone and Goat Island, and just west of Burnie there are conglomerates and quartzites frequently highly contorted and often schistose in structure which have been assigned to a pre Cambrian age (Stephens 1874) on very little evidence as similar rocks have been described in detail for the Smithton area (Nye Finucane and Blake 1934) who maintain that they lie probably conformably below the Slate group

A N Lewis (1923 1938) has also described quartzites in the south west of the State and at Mt Anne he shows that they overlie slates which he referred to the Dundas Series

Lithological characters are thus of very little use in determining the age of these sandstones and quartzites

THE CAMBRIAN (OR LOWER SLATE GROUP)

These slates which are very widespread and economically important have been described from many localities Several groups have been recognised e g Dundas Slates Balfour Slates and Bischoff Slates

L K Ward first described these rocks at Dundas in 1909 He states that from the evidence supplied in the district he could not correlate them accurately with other series but indicated that they are succeeded by a conglomerate series

This description and the one by L Hills covering the Read Rosebery area to the north of the Dundas area (Hills 1915) must now be read subject to the more recent view that the igneous suite are considerably later and entirely intrusive into the sedimentary group There is a general opinion that the Dundas Slates underlie the West Coast Range Conglomerate Series L Hills (1915 p 4) also records limestone interbedded with the slates at Hercules Mine and Nye (1923) has given us the most complete description of them at Magnet (with analyses and petrographical commentaries) The latter distinguishes several divisions in the slate series there developed namely a slate, a chert a felspathic breccia and a micaceous breccia Nye identified the Dundas slate series as defined by Ward and also a new group which he termed the Bischoff series He stated that outcrops were too infrequent to enable the different stages of the two series to be mapped but regarded the Dundas series as being the older Reid, working at the same time on the Mt Bischoff portion of this field describes the Bischoff slates and records an unconformity between them and the underlying Dundas series (Reid 1923) Later however, Reid identified the Bischoff slates at Dundas but on lithology only and considered them as there developed to be older than the Dundas series (Reid 1925)

The Dundas slates are usually described as purple to reddish and occasionally grey to black and appear to underlie the conglomerates and quartzites of the Magog Group Twelvetrees (1908) described the relationship at the Humboldt Mine under the Needles Ward at Dundas (1909) Twelvetrees at Gunn s Plains Blythe River Penguin Alma (1909) Ward at Mt Balfour (1911) Reid at Round Hill and Wilmot (1919) Nye at Adamsfield (1929) and A N Lewis at Pine Hill and Mt Anne (1923 and 1940)

The downward succession of these old rocks is very obscure and has only been recorded in published work in Nye and Blake (1938) These authors refer to pre Dundas rocks and assign to this group the Smithton quartzites Farrel slates Balfour slates Arthur River slates and Hatfield Plains slates One single fossil has been found in each of the last two slate series which have been assigned an Upper Cambrian age (Chapman 1925 and 1928) on this very slender evidence

Hall s graptolites were found in the Dundas slates and assigned an Ordovician age (Hall 1902 Keble 1928) but doubt (Thomas 1945) has been cast on the identification of these forms as graptolites

The discovery of hydroid remains at Dundas together with some fragmentary remains of trilobites (Thomas and Henderson 1945) enables the Dundas Slates to be correlated with similar beds of Middle Cambrian age in Victoria The black slate and the interbedded volcanic tuffs ashes and agglomerates show a very close lithological resemblance to rocks of similar age in Victoria

Although local names have been given to the slates as developed in the different localities it seems that broadly they can be considered as a Lower Slate Series There is no palaeontological or stratigraphical evidence which renders this impossible or even improbable

Some of the subdivisions of this group may be usefully summarised as follows —

Farrel Slates This was set up by L K Ward in 1908 to include the dark slates and sandstones of the Mt Farrel district which appear to be older than the Silurian rocks of this district

Dundas Series (L K Ward 1909) is one of considerable thickness, composed of slates, generally red when weathered, but grey, green and black when unweathered, with fine grained breccias of volcanic material (basic felspar and augite) and cherts, tuffs, and basic volcanic rocks (Nye 1923) It has generally a faulted relationship to the younger rocks

In the Rosebery district (K J Finucane 1932) dark slates and quartzites occur in addition to the above types and in the Smithton district (Nye, Finucane and Blake) a limestone bed and thick dolomites are interbedded with rocks supposed to belong to this group

Beneath the Dundas Series in the Smithton district (Nye etc, 1934) dark slates and quartzites and fine conglomerates occur apparently conformably and extend eastward to the white quartzites and dark slates of Sisters Hill which had previously been referred to the Proterozoic

Balfour Series This series was described by L K Ward in 1910 (Bulletin No 10) for the North Western district It comprises light coloured slates quartzites and fine conglomerates intruded by granite and by basic dykes

Bischoff Series (Nye 1923) consists of alternating beds of slates and sandstone with subordinate conglomerates and breccias No fossils have been found, but it is considered younger than the Dundas Series

Rosebery Series (K J Finucane 1932) includes the slates and quartzites of the Rosebery area, which are apparently stratigraphically beneath the Dundas Series

THE RELATIONSHIP OF THE CAMBRIAN TO THE PROTEROZOIC

The Proterozoic Rocks have been described in some detail by W H Twelvetrees (Proc A A A Sc 1907) and by L K Ward (Proc Roy Soc Tas, 1909) The latter recognised two series from the evidence in the Surveyor Range where an upper series of quartzites unconformably overlie quartz and mica schists

The basis of the separation of the Proterozoic from the Lower Palaeozoic has been the lithological character and their structural relationship with other series Their schistose nature is more pronounced than that of the younger rocks which according to most workers follow them unconformably But very few areas showing this relationship have been recorded or examined in detail At Frankford (Nye 1928) a contact of conglomerates with Pre Cambrian schists can be seen, and he also states that a contact, not examined in detail has been seen at De Witt Island off the South Coast

In the Smithton area (Nye Finucane and Blake 1934) a group of slates was correlated with the Dundas Series (p 53) Above this is a Dolomite, and beneath it a Chert Stage Beneath the Chert Stage is a considerable thickness of rock divided into —

2 Grey-green quartzite stage
1 White quartzite stage

It is considered that the grey green quartzite stage conformably underlies the Dolomite stage (or where absent the chert substage) but there may be an unconformity between the grey green quartzite and the underlying white quartzite stage although these may form one stage

These quartzites are correlated with those of the Sisters Hill (p 25) of which they state This suite of rocks has been ascribed by Loftus Hills to the Upper Proterozoic but they may represent transition beds between the Upper Proterozoic and Lower Palaeozoic or even be Lower Cambrian

The separation of the Proterozoic rocks from the Lower Palaeozoic as shown on the Geological Maps of Tasmania cannot be regarded with confidence for even on the road between Lake St Clair and Queenstown there are fossiliferous beds which are Upper Ordovician or Lower Silurian in the centre of a big area coloured as Proterozoic

Summary and Conclusions

It is obvious from the foregoing that there is need for much detailed structural palaeontological and stratigraphical research before the sequence of the Lower Palaeozoic rocks of Tasmania can be solved Exhaustive collections are essential before the age of the various groups can be determined Until this information is available the major structural features cannot be studied and there is no doubt that these are complex and of sufficient magnitude to have complicated the task of deciphering the stratigraphic succession

The information Tasmania can yield concerning the development of the Tasman Geosyncline is most interesting The succession—conglomerates to sandstones or quartzites and then limestones and shales—is well marked not only in the Ordovician but also in Silurian Devonian times The rapid alternations both vertically and laterally have however added to the difficulties of correlation

There is probably a gradual passage from the Proterozoic to the Cambrian resembling conditions as found in South Australia if the Smithton area is considered as typical

The volcanic activity of Cambrian times and the development of thick slates and shales following the cessation of this extrusive phase is matched by similar conditions in Victoria In both States these slates are fossiliferous only at the lower horizons In Victoria the Ordovician is mainly a shallow water facies with relatively thin graptolitic shales representing deeper water conditions In Tasmania the Ordovician commences with the conglomerates then sandstones and limestones and the comparable conditions are in Central Australia rather than Victoria

The Silurian Devonian is initiated in Western Tasmania by the West Coast Range Conglomerates which are succeeded by sandstones limestones and shales all showing the characteristics indicative of rapidly alternating conditions of sedimentation In Victoria there is a well defined lithological break between the Upper Ordovician and Silurian and thin interbedded conglomerates are only sporadically developed in the lower Silurian (Keilorian) rocks Higher in the sequence lenticular limestones and conglomerates approximately mark the boundary between Silurian and Devonian Conditions in Tas mania indicate more fluctuating depths than in Victoria but the deeper water facies as developed in the Walhalla Synchnorium is matched by the lithologically similar Mathinna series , both having shallower water beds with plant remains

Without more detailed knowledge of Tasmanian stratigraphy and structure, it is difficult to draw closer comparisons It is thought, however that the identification of three major groups will be of help, but the following summary merely serves to show the gaps in our knowledge —

1 The relationship of the Cambrian to the Proterozoic is not known with certainty
2 There is a thick development of slates frequently associated with basic volcanic activity which can be considered as of Cambrian age (It is likely however that there is also a later development of basic rocks comparable with those at Waratah Bay in Victoria i e post Upper Silurian at least)
3 The Ordovician is initiated wherever studied in detail by conglomerates succeeded by beds containing the Tasmanocephalus fauna and by limestones with large cephalopods The conglomerates must be low in the Ordovician (Tremadocian), but the age of the upper beds of this group is not known If the limestones on the Mersey River and the Queenstown flux quarry are Upper Ordovician the age of the succeeding conglomerates in all probability is Silurian The King River Series are probably of the same general age as these limestones which however according to Dr D Hill may also doubtfully be Silurian
4 The exact age of the West Coast Range Conglomerates is not known They overlie unconformably beds probably of Upper Ordovician age (or more doubtfully Silurian age) and are succeeded conformably by the Gordon River Limestone Series of undoubted Silurian age Higher still in the sequence are the Eldon Beds and the Pleurodictyum bearing beds at Zeehan which may be Lower Devonian in age and may thus be correlated with the Mathinna Slates

This contribution is an attempt to review the literature and although it perhaps errs in over simplifying the Lower Palaeozoic Record it also indicates some of the problems yet to be solved Much of the work of the Tasmanian Geological Survey remains in manuscript form a state of affairs that should be remedied as it is difficult to gain access to these papers It is thus possible that some of this later work has unintentionally been omitted from this discussion

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5—A Survey of Vegetable Matter in the Wool Clip of S.E. Australia

By S. J. CHURCH, M.Sc.

[Read 13th June 1946]

Introduction

Leaves, twigs, fruits and other fragments of vegetable matter are picked up in varying quantities by the fleece during the activities of sheep on pasture The presence of this vegetable matter may interfere with the normal processing of the wool Moreover its presence in the finished material is highly undesirable and every effort has to be made to remove it during processing Its removal frequently requires special treatment of the wool involves extra handling, and may damage the wool in some degree

The presence of vegetable matter in wool, then constitutes a problem to the processor of wool It also constitutes a problem to the wool appraiser who must decide the quantity of vegetable matter present, and its influence on the costs of processing and the value of the finished product For any detailed study of these problems information on the nature of the vegetable matter to be found in wool is an obvious requisite

A survey of vegetable matter found in the New South Wales wool clip was published by Milthorpe (4) A similar survey has now been completed for wools originating from Victoria South Australia Tasmania, and those districts in New South Wales adjacent to the River Murray

General Procedure

Samples were drawn more or less at random from wools delivered to Victorian Tasmanian and South Australian Appraisement Centres Work was very largely confined to samples which showed an appreciable vegetable matter content—of the order of 1 per cent or more of the greasy weight For the most part the wool was scoured prior to examination The vegetable matter was removed by hand and identified as far as possible In each case the identification of type specimens was checked by authorities at the Botany School University of Melbourne or the National Herbarium Melbourne These type specimens were retained and other specimens were identified by comparison with them

The nomenclature and classification of Black (1) have been followed as far as possible For species not described by Black the description of Ewart (3) has been used The common names presented are those listed by C S I R (2)

The nearest town to the property from which the wool was derived has been taken as being the place of origin of the wool On the basis of average annual rainfall the area covered by the survey has been divided into four zones as set out in fig 1 The samples have been allocated to the individual zones according to the places of their origin

No attempt was made to assess quantitatively the amounts of the different types of vegetable matter present in the samples

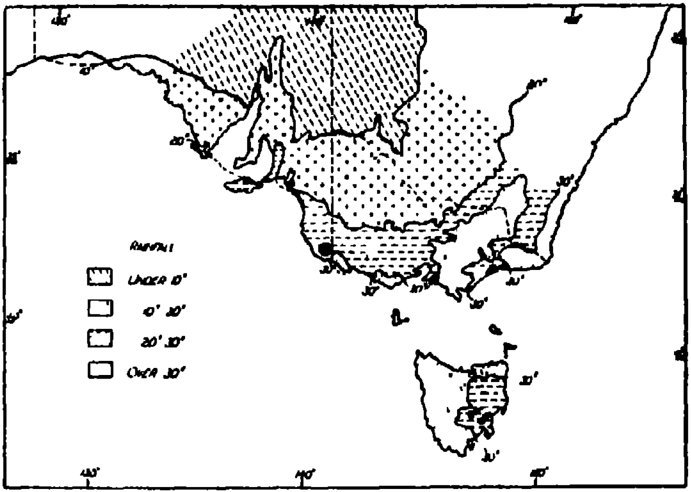

Fig 1—Map showing *area covered* by Survey Isohyets from map published by Meteorological Branch, Commonwealth of Australia, showing average annual rainfall based on figures up to 1938

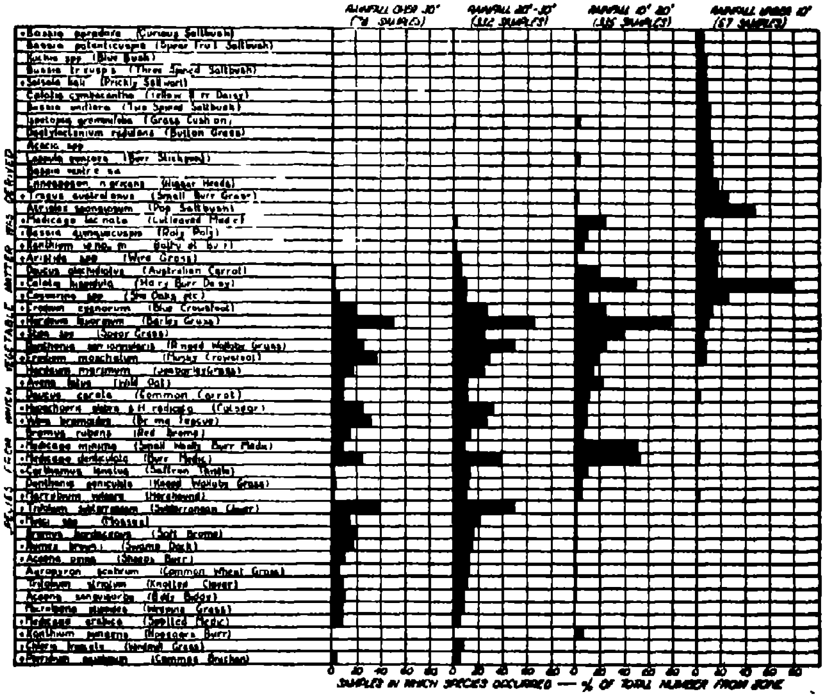

Fig. 2—Relation of type of vegetable matter found in samples *to average* annual rainfall Only those species included from which vegetable matter occurred in 5 per cent. or more of the samples from one or more zones.

Results

Over 800 samples were examined in all. Vegetable matter from 123 species of plants was identified. Mention is made here only of those species from which vegetable matter occurred in 5 per cent. or more of the samples from one or more of the zones. There were 51 of these species which are listed in fig. 2. Twenty-seven of them are recorded by Milthorpe (4). Vegetable matter of the remaining 24 has not previously been recorded as occurring in wool.

DISTRIBUTION OF SPECIES.

The distribution of the various types of vegetable matter in relation to the average annual rainfall is included in fig. 2, which sets out the proportions of the samples from each zone in which the different types of vegetable matter occurred. As might be expected, there is a distinct relationship between the average annual rainfall of the area from which the wool originated, and the type of vegetable matter found in it.

Nine species, all drought resisting types, were found only in samples from the driest districts, and 12 species, all typical of higher rainfall areas which were found in samples from the two wettest zones were almost entirely absent in samples from the dry districts. Hairy Burr-Daisy (*Calotis hispidula*) and Pop Saltbush (*Atriplex spongiosum*) were the most common types found in these dry areas, occurring respectively in 79 per cent. and 47 per cent of samples. Grasses and Legumes were not common among the other species, Composites and Chenopods occurring most frequently.

The vegetable matter in the samples from the two wettest zones was of closely similar character, 30 of the 34 species found in samples from these zones being common to each Most of these species, such as Biddy-Biddy (*Acaena Sanguisorba*), Mosses (*Musci. spp.*), Swamp Dock (*Rumex Brownii*), etc., are typical of the vegetation of areas of higher rainfall. Fragments of Grasses and Subterranean Clover (*Trifolium subterraneum*) occurred in a very high proportion of the samples. Wild Carrot (*Daucus Carota*), and the two common species of Crowsfoot (*Erodium spp*) were three other types found almost as frequently. The Medics (*Medicago spp*) were recovered from a smaller proportion of samples

In the samples from the zone with the average annual rainfall of 10 to 20 inches, the greatest variety of types of vegetable matter was recovered, species common to both the driest and the two wettest zones being found. As in the two wettest zones, the outstanding characteristics of this zone was the high proportion of samples in which fragments of the Grasses occurred, the most important being common Barley Grass (*Hordeum leporinum*). Three species of Medic were also recovered very frequently. They occurred in a much higher proportion of the samples from this zone than from any other. Drought resisting types occurred in a smaller proportion of samples than in the driest zone, though Hairy Burr-Daisy (*Calotis hispidula*) appeared in as many as 50 per cent. of those examined. Australian Carrot (*Daucus glochidiatus*) and the two species of Crowsfoot occurred more commonly than in the driest zone, but less commonly than in the two wettest zones.

NATURE OF VEGETABLE MATTER RECOVERED.

The vegetable matter found with the 27 species recorded by Milthorpe (4) was similar to that described by her. The nature of the material found with the other 24 species is indicated in the following notes and figs. 3-26. Details of the features used in identifying the material are included.

GRAMINEAE*

Danthonia semiannularis (Labill.) R. Br., Ringed Wallaby Grass, fig. 3. Material recovered: Spikelets, flowers Identifying features: Spikelet of two outer glumes and 6-9 flowers, flowering glume about 3 mm. long bearing three conspicuous rings of hairs and three awns, the central awn brown and twisted and longer than the lateral ones; palea notched at apex.

D geniculata, J M Black, Kneed Wallaby Grass, fig. 4. Material recovered: Spikelets, flowers Identifying features: Spikelets of four to five flowers; palea blunt and hairy on back; otherwise as *D semiannularis*, except that awns shorter and central awn not longer than lateral ones.

Hordeum marikinum, Huds, Sea Barley Grass, fig 5. Material recovered: Inflorescence, groups of spikelets, spikelets Identifying features: Fragments of inflorescence with three one-flowered spikelets at each node; central spikelet fertile, 6-7 mm long and almost sessile; lateral spikelets sterile, 5 mm. long and stalked; outer glumes in each case awnlike in shape, arranged in pairs and not ciliate; flowering glumes inrolled at the base with long, rough awns.

Microlaena stipoides (Labill), R Br, Weeping grass, fig. 6. Material recovered: Spikelets, flowers Identifying features: Spikelets one-flowered, about 30 mm long; first pair of outer glumes minute, second pair hard and rough, each tapering into a long awn and bearing a tuft of hairs at the base; flowering glume short and inconspicuous

Agropyrum scabrum (Labill), Beauv, Common Wheat Grass, fig. 7. Material recovered. Spikelets, flowers Identifying features: Spikelets wedge-shaped, 5-7 cm long, including awns with six to twelve flowers; flowering glumes narrow, rigid, rough, with awns about 3 cm long.

Bromus rubens, L., Red Brome, fig. 8. Material recovered: Spikelets, flowers Identifying features: Spikelet reddish-purple with five to eight divergent flowers, the awned flowering glume 2-5 cm long, roughened on the back and curving outwards when mature

B hordeaceus, L., Soft Brome, fig 9 Material recovered: Spikelets, flowers Identifying features Spikelets five to eight flowered; flowering glumes short and ovoid, about 6 mm long, bearing an awn about the same length.

Pappophorum nigricans (R Br), Beauv, Nigger-heads, fig. 10. Material recovered: Fertile flowers Identifying features: Flowering glume stiff, rounded, bearded at the base with distinct nerves ending in ciliated awn 4-6 mm. long

Dactyloctenium radulans (R Br), Beauv, Button-grass, fig. 11. Material recovered: Fragments of inflorescence Identifying features: Inflorescence of three to five flowered spikelets, compressed, sessile, in two rows along one side of the axis, the end of which projects in a point; spikelets 5 mm. long, outer glumes unequal

CHENOPODIACEAE

Bassia spp. Material recovered: Perianths enclosing fruits, stems.

B patenticuspis, And, Spear-fruit Saltbush, fig 12. Identifying features: Perianth tube slightly hairy, bearing two long divergent spines, and one tubercle; whole ovate to oblong in shape with hollow base.

B ventricosa, J. M Black, Common name unknown, fig. 13. Identifying features: Perianth tube 2-3 mm. in diameter, and slightly hairy, with four spines; two short and inconspicuous, and two 3-5 mm. long, sharp and pointed.

B tricuspis, F V M, Three-spined Saltbush, fig 14. Identifying features: Perianth tube broad and spreading at the base, bearing three long spines arranged at right angles to each other and parallel to the stem.

---

* Flowering glume and palea enclose the grain or flowering parts, the whole known as a "flower." Spikelet consists of one or many flowers enclosed by empty bracts or glumes,

B. uniflora (R.Br.), F.V.M., Two-spined Saltbush, fig. 15. Identifying features: Perianth tube almost as broad as long, with circular, hollowed base, covered with short dense hairs and bearing two divergent spines, one with a tubercle at the base.

Atriplex spongiosum, F.V.M., Pop Saltbush, fig. 16. Material recovered: Perianths with soft material destroyed. Identifying features: Matrix of perianth, reticulate, hard and dry, with fibrous outgrowths, basket-like in appearance, about 1 cm. long.

Kochia spp., Bluebush, fig. 17. Material recovered: Perianths enclosing fruits. Identifying features: Perianth flattened on the top with five horizontal wings attached to rim spreading outwards, also united or singly cleft

COMPOSITAE

Isoetopsis graminifolia, Turcz, Grass Cushion, fig 18. Material recovered: Fruits. Identifying features: Fruit a cylindrical achene, hairy, about 2 mm. long, bearing a pappus of eight to twelve obtuse scales about the same length

Calotis cymbacantha, F.V.M., Yellow Burr-Daisy, fig 19 Materials recovered: Fruits. Identifying features. Fruit an achene, flat, tuberculate, with two divergent awns, boat shaped at the base and set at right angles to the flat faces of the achene, enclosing the convex apex.

BORAGINACEAE

Lappula concava, F.V M, Burr Stickseed, fig 20 Material recovered: Nutlets Identifying features Nutlet with raised margin bearing eight to ten barbed prickles, the back concave and rough (4 nutlets from each fruit).

UMBELLIFERAE

Daucus glochidiatus (Labill.), Fisch, Mey et Ave-Lall, Australian Carrot, fig. 21. Material recovered: Fruitlets Identifying features Fruitlet with three inconspicuous primary ribs and four prominent secondary ribs, the latter bearing long bristles barbed at the tip. (Two fruitlets from each fruit.)

D Carota, L., Wild Carrot, fig 22 Similar to above, but fruitlet usually smaller and prickles not barbed.

ROSACEAE

Acaena Sanguisorba (L.F), Vahl, Biddy-Biddy, fig 23 Material recovered Groups of fruits, fruits. Identifying features Fruits in dense globular heads, about 2 cm in diameter; each fruit bearing four long prickles barbed at the tip.

LEGUMINOSAE

Trifolium striatum, L, Knotted Clover, fig 24 Material recovered: Fruits Identifying features: Fruit almost globular in shape, covered with fine, soft hairs and bearing five spreading rigid teeth.

Acacia, spp., fig. 25. Material recovered: Fragments of leaves, seldom very many present. Identifying features: Typical features of Acacia leaves of phyllode or bi-pinnate types.

BRYOPHYTA (Non-Flowering Plants)

Musci spp, Mosses, fig. 26. Material recovered: Stems bearing leaves. Identifying features: Features typical of vegetative parts of mosses.

MANNER OF RETENTION OF MATERIAL IN THE WOOL.

The fragments of vegetable material discussed above, all possess features which assist their retention in wool. With the fragments of the grasses, the sharp points of the flowering glumes, the rough surfaces of the awns and the glumes and the hairs covering them act in this manner. The other types of vegetable material possess smooth or barbed spines, prickles, or fibrous outgrowths, scaly appendages or fine leafy stems.

Of the species which were not recorded by Milthorpe, two—Pop Saltbush (*Atriplex spongiosum*) and Biddy-Biddy (*Acaena sanguisorba*) were striking. Both were always found in great quantity in the samples from which they were recovered. The perianths of Pop Saltbush from which the soft portions had disappeared, were very hard and impregnated with dirt. They became surrounded by a thick felt of wool, and appeared similar to the burrs produced in wool by fruits of the Medics. The entire heads of Biddy-Biddy were firmly embedded in the wool, or, if the head was broken apart, the individual fruits, when very plentiful, appeared as a brown crust on the surface of the fleece. Any other wool which came in contact with this crust immediately became entangled with it.

Acknowledgments

I wish to thank the Australian Wool Realisation Commission for permission to publish this paper. To Dr. R. H Watson, Officer-in-Charge, Australian Wool Realisation Commission Testing House, I am particularly indebted for advice and criticism in compiling the manuscript. I also wish to thank those other members of the staff of the Testing House who have assisted me in the collection of the vegetable matter, together with members of the staff of the Botany School, University of Melbourne, and the National Herbarium, who have assisted me in its identification

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2 C S I R Standardised Plant Names Bull No 156 1942

3 Ewart A J Flora of Victoria 1930

4 Milthorpe, F J Vegetable Matter in the New South Wales Wool Clip, Central Wool Committee Testing House, Sydney, 1943

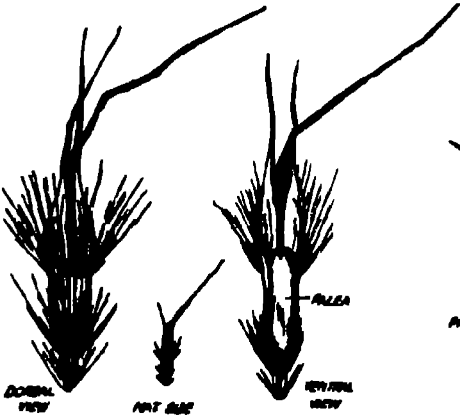

Fig 3 D Semiannularis
Flowering Glume

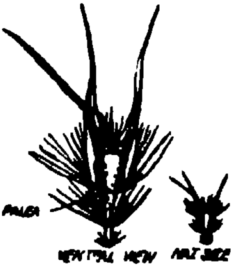

Fig 4 D Geniculata
Flowering Glume

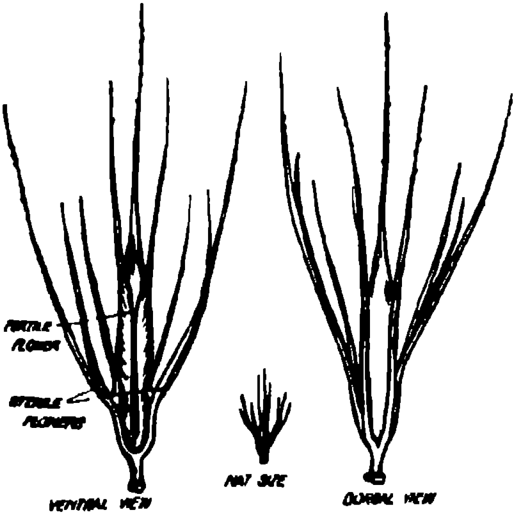

Fig 5 H Marinum
3 Flowered Spikelet

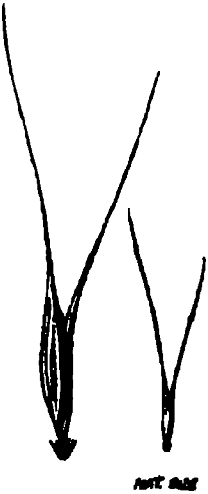

Fig 6 M Stipoides
Inner Glumes

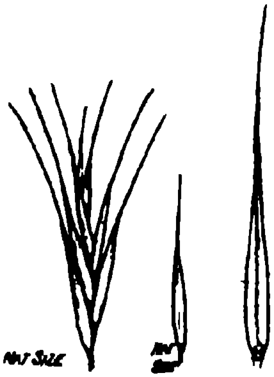

FIG 7 A SCABRUM - SPIKELET & SINGLE FLOWER

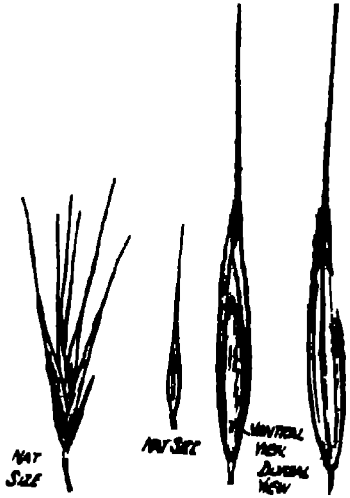

FIG 8 B RUBENS SPIKELET & SINGLE FLOWER

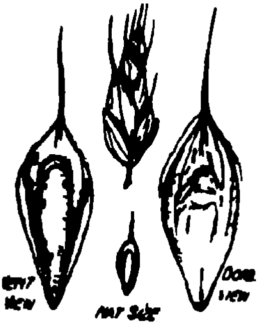

FIG 9 B HORDEACEOUS SPIKELET & SINGLE FLOWER

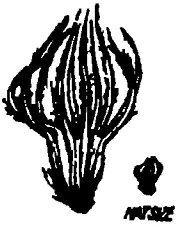

FIG 10 E NIGRICANS FLOWERING GLUME

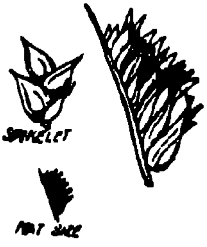

FIG 11 D RADULANS INFLORESCENCE & SPIKELET

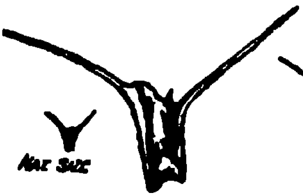

FIG 12 B PATENTICUSPIS - PERIANTH TUBE

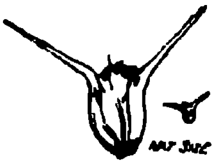

FIG 11 A VENTRICOSA PERIANTH TUBE

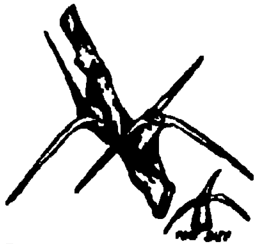

FIG 14 B TRICUSPIS PERIANTH TUBE & STALK

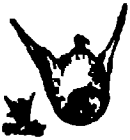

FIG 15 B UNIFLORA - PERIANTH TUBE

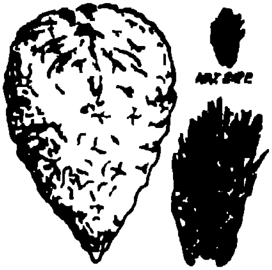

FIG 16 A SPONGIOSUM IMMATURE & MATURE FRUIT

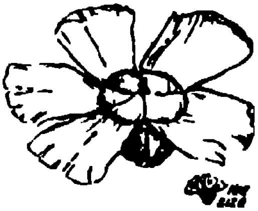

FIG 17 KOCHIA SPP PERIANTH TUBE

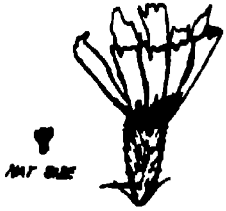

FIG 18 I GRAMINIFOLIA SINGLE ACHENE

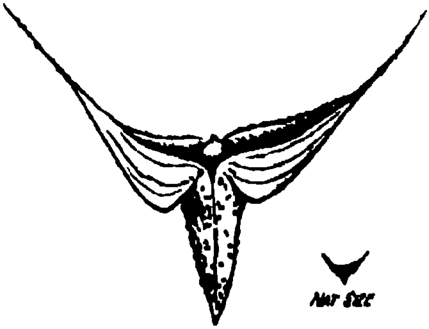

FIG 19 C CYMBACANTHA SINGLE ACHENE

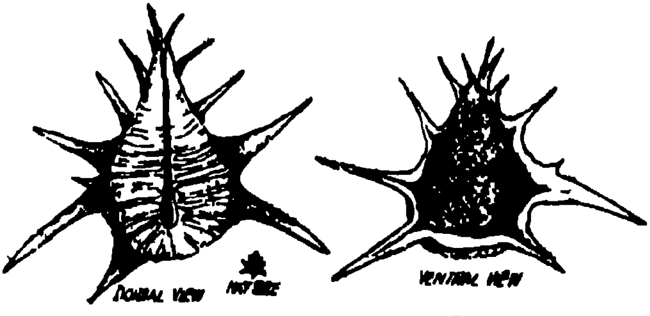

FIG 20 L CORNUTA SINGLE FRUITLET

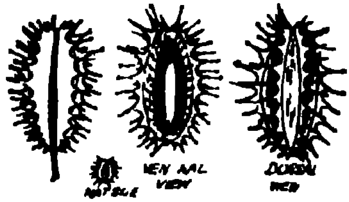

FIG 21 D GLOCHIDIATUM PAIRED & SINGLE FRUITLETS

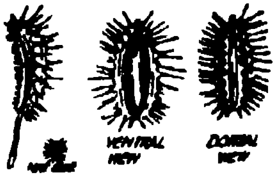

FIG 22 D CAROTA PAIRED & SINGLE FRUITLETS

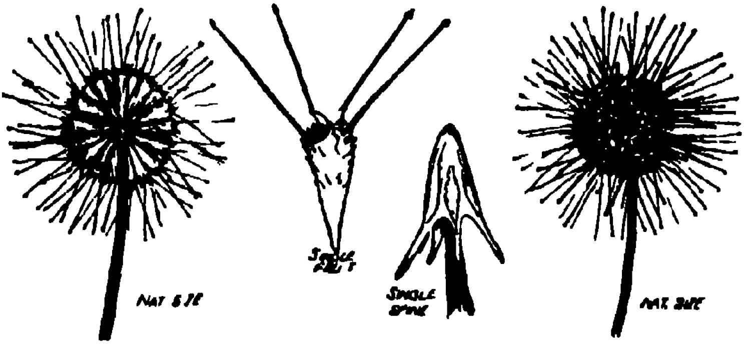

FIG 23 A SANGUISORBA FRUITING HEAD ENTIRE & IN SECTION

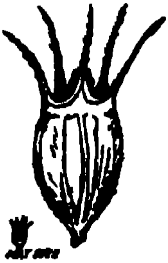

FIG 24 T STRIATUM FRUIT

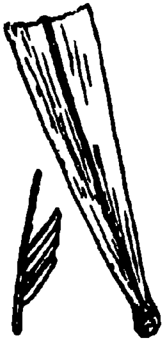

FIG 25 ACACIA SPP LEAF FRAGMENTS

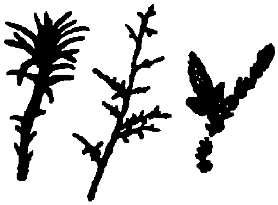

FIG 26 MUSCI SPP – THREE TYPES

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6—*Late Quaternary Changes of Sea-Level at Rottnest Island, Western Australia*

By CURT TEICHERT, D.Sc.

[Read 10th October, 1946]

Abstract

Rottnest Island, situated eleven miles off the coast of Western Australia near Fremantle, consists predominantly of dune rock of presumably late Pleistocene age. Some marine limestones, including a fossil coral reef, are probably of slightly greater age. Part of the island is occupied by a series of salt lakes which in early Recent time formed an embayment of the sea. Erosional features such as benches and undercut cliffs as well as the existence of shell deposits at various heights above sea-level suggest lowering of sea level in the post-Pleistocene of 10-11 feet by two steps interrupted by stillstand periods at about 5 feet and 2 feet above present sea level.

Introduction

Although Rottnest Island is one of the most popular holiday resorts in Western Australia and within easy reach of Perth and the metropolitan area, no more than passing references to its geology may be found in existing literature. The following notes are the result of two visits to the island in 1938 and 1945 together of about three weeks' duration. Geological observations on the island are facilitated by good maps. A map on the scale 16 chains = 1 inch is available from the Lands Department of Western Australia and during the war the Department of the Army issued a contour map on the scale of 4 inches = 1 mile. A very useful little map about ½ mile = 1 inch, is on distribution at the Government Tourist Office of Western Australia. Finally Admiralty Chart 240 "Approaches to Fremantle," was found very helpful. It gives Rottnest Island and surrounding reefs and waters on the scale 2 500 feet = 1 inch.

My thanks are due to Mr William Brown now of the Australasian Petroleum Company Melbourne who assisted me in various ways on a number of excursions to different parts of the island in December, 1945 and to Mr Gordon Smith of the University of Western Australia who helped to take a line of soundings across Government House Lake. Professor E de C Clarke and Dr R W Fairbridge, of the University of Western Australia had the kindness to read through the manuscript and made a number of valuable suggestions for which I am much indebted to them.

General Description

Rottnest Island lies in the Indian Ocean eleven miles off the coast of Western Australia slightly north of the latitude of Fremantle. Its greatest length is in an east west direction from Philip Point to Cape Vlaming (over 6½ miles) its greatest width in a north south direction between Parker Point and Point Clune slightly less than 3 miles. It covers an area of approximately 7 1/3 square miles.

The island rises from the continental shelf inside the 10 fathom line which in this vicinity bulges oceanward to a distance of almost 20 miles from the mainland (fig 1). The coasts are partly sandy, but partly formed by cliffs, and the surface of the island is irregularly hilly. The highest elevation is 154 feet, situated almost in the centre of the island and bearing the principal lighthouse, and hills higher than 100 feet are found in many parts of the island.

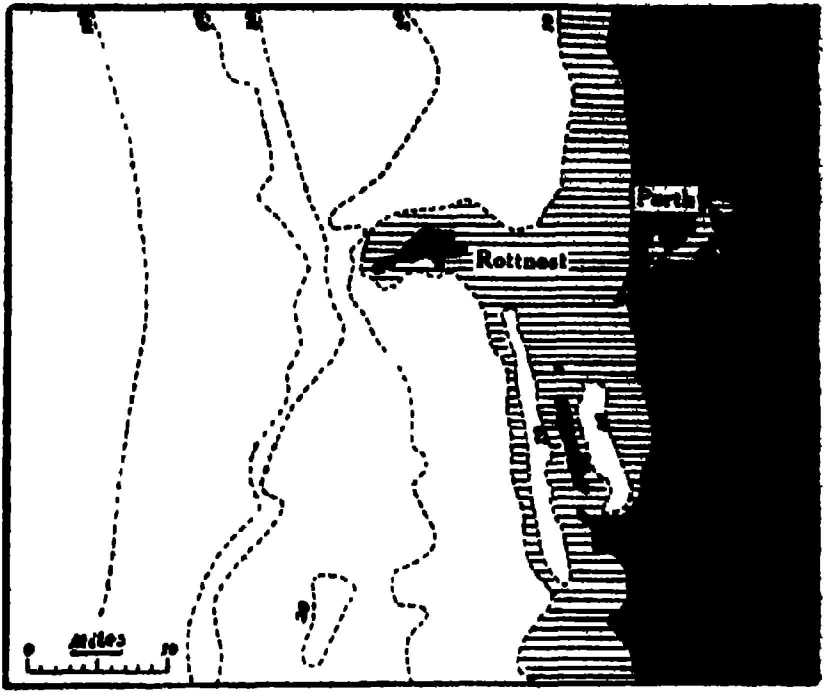

Fig. 1.—Part of the coast of Western Australia, showing mainland coast, shelf, and Rottnest Island. (Depths in fathoms.)

Much of its surface is covered by blown sand, although solid rocks crop out in many places and are exposed intermittently all along the coasts. These rocks are limestones and calcareous sandstones of what in Western Australia is generally known as the "Coastal Limestone Series" and will be described in more detail below.

One of the most attractive features and one to which the island owes much of its popularity as a holiday resort, is a series of salt lakes in the eastern half There are four principal lakes—Government House Lake, Serpentine Lake, Lake Herschell, and Lake Bagdad—in addition to a few smaller ones. Together the lakes cover an area of about 0.8 square miles, or about one-ninth of the surface of Rottnest Island. A line of soundings taken across Government House Lake indicated the existence of a fairly flat bottom at depths of from 23 to 28 feet

The water of all the lakes is highly saline. In summer time the lake levels fall, owing to excessive evaporation and the salinity probably increases correspondingly. During the rainy season in winter time the lakes rise and the salinity must be presumed to be lower.

The following analysis of a sample of water taken from Government House Lake on 23rd January, 1940, has been made available by the Rottnest Board of Control:

	$^0/_{00}$
Calcium carbonate ($CaCO_3$)	0.37
Calcium sulphate ($CaSO_4$)	4.60
Magnesium sulphate ($MgSO_4$)	11.04
Sodium nitrate ($NaNO_3$)	Nil
Magnesium chloride ($MgCl_2$)	17.19
Potassium chloride (KCl)	3.40
Sodium chloride ($NaCl$)	108.67
Iron and aluminium oxides (Fe_2O_3 and Al_2O_3)	0.50
Silica (SiO_2)	Traces
Total	145.8 $^0/_{00}$
Total hardness	31.0
Total magnesium	6.6

pH = 8.4.

Encircling the lakes is an almost continuous platform of varying width which is submerged during the wet season, but dry in summer. It is carved out of the dune limestone and its position seems to be at present mean sea-level or very slightly higher. It is covered with fossil shells, mostly gastropods and pelecypods, and shell deposits are also found in the vicinity of the lakes up to a height of several feet above the highest present lakes level.

Lastly we find all over the island indications of erosive activity by the sea at various levels above present sea-level: erosion benches, notches, platforms, and raised beaches. In this respect Rottnest Island is of outstanding interest and there is probably no better place in Western Australia for the study of recent movements of sea-level. Brief references to wave-cut platforms, undercut lake cliffs, and "raised" shell beds may be found in papers, chiefly concerned with mainland features, by Somerville (1921), Aurousseau and Budge (1921), and by Clarke (1926), but no systematic description of these features has as yet been attempted.

Tides and Levels of Reference

As everywhere along the coasts of south-western Australia, the tides at Rottnest Island are irregular and highly variable. "Between North-West Cape and Cape Leeuwin, the tides are greatly influenced by the wind, varying as much as 2 feet with off-shore and on-shore winds, the former reducing the sea-level. The rise and fall varies from 2 to 5 feet. The higher sea-level is attained in June and exceeds the lower sea-level, which is attained in November, by about 2 feet" (*Australia Pilot*, Vol. V).

It is common practice to record the position of shore-line features with reference to either mean sea-level or else low water level or Admiralty Datum. Under certain conditions this procedure is apt to lead to confusion, because, depending on the range of the tides, synchronous and homologous shore features may appear at very different heights above mean sea-level or above datum. The same sea might heap up a beach ridge 5 feet above datum in one place along a coast and at 25 feet or 35 feet above datum a few hundred miles farther on. However, in both places the position of the beach ridge would be at or slightly above high water level and it seems, therefore, more natural to fix the height of shore line features with reference to that tide level to which they owe their origin. High water level

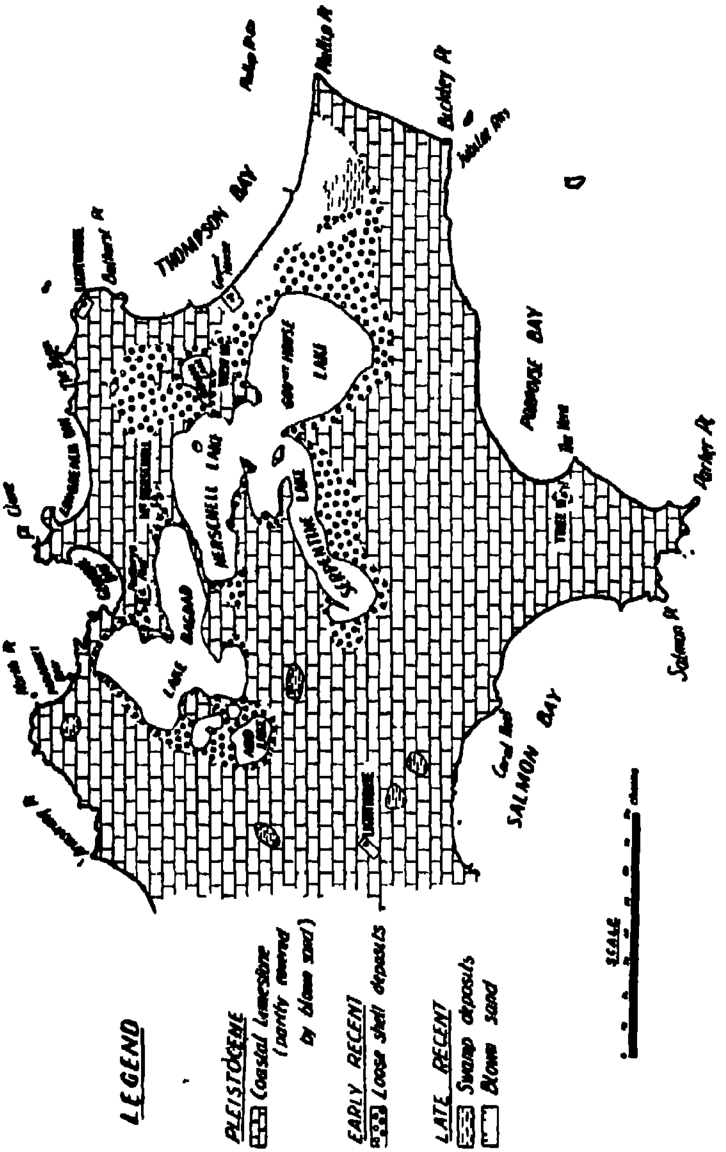

Fig. 2.—Geological map of eastern portion of Rottnest Island. (North is left.)

springs (H.W.L.S.) should be the level of reference for such features as beach ridges; low water level springs (L.W.L.S.) should be the level of reference for rock benches and coral reef tops, and so on. In case of doubt recourse could always be had to L.W.L.S. or Admiralty datum. In all cases a clear statement of the tidal conditions in the area under consideration should accompany or precede the description of shore line features.

All levels recorded in this paper were measured with an Abney level, but the tidal range on Rottnest Island being small and the time of arrival of the tides irregular, high water marks are usually neither clear nor very reliable. An error of one foot, or even two feet, may therefore be easily introduced in measurements which have high water level as their level of reference. In general, it may be assumed that in this paper H.W.L.S. is 4-5 feet, L.W.L.S. 0-1 foot above datum.

Coastal Limestone Series

The bulk of Rottnest Island consists of limestones and calcareous sandstones of the Coastal Limestone Series. Some of these rocks are marine, some are of aeolian origin, but the latter by far outweigh the former in importance. Dune limestones crop out in many places on the island and form most of the coastal cliffs. In some places the dune limestone can be seen to rest on marine, fossiliferous limestone. A deep bore has penetrated this limestone series to a depth of 200 feet below sea level, so that it may be assumed that the sea-floor in the vicinity of the island, approximately down to the 30 fathom line, consists of the same rocks.

The best place to study the older marine limestones of the island is Salmon Bay, in the middle of the south coast.

THE FOSSIL CORAL REEF IN SALMON BAY

In the middle of Salmon Bay, on the south side of the island, is a low, rather inconspicuous, limestone cliff, forming an exposure about 300 yards long. This cliff rises from a limestone platform at approximately low water level, the platform sloping seaward at a low angle. At approximately mean high water level there is a narrow bench not more than a few feet wide and just above this level the cliff is in most places strongly undercut. The top of the cliff is almost horizontal at a height of about 10 feet above L.W.L.S. (Plate V, fig. 1).

The eastern half of the cliff consists of an emerged coral reef which rises to heights between 6 ft. 6 in. and 8 ft. 3 in. above the low water level platform. This platform continues to the east of the cliff where it can be followed at and below L.W.L. under a cover of beach sand. As far as can be seen it consists of solid coral limestone for a distance of at least another 30 or 40 yards and the coral reef must originally have extended in this direction. The predominating forms in the reef limestone are branching species of *Acropora* mixed with some foliose types, and in some places large colonies of *Platygyra lamellina* and of *Favites favosus* may be seen.

The thickness of this reef is possibly not great, because in some places it does not seem to extend below L.W.L. and can be seen to be underlain by calcareous, fossiliferous, though non-coralliferous, sandstone.

The slightly irregular surface of the reef is overlain by bedded, non-coralliferous limestone, or calcareous sandstone, which has a rather uniform thickness of 2 ft 9 in This bed contains many shells, particularly gastropods among which *Turbo stamineus* is very common.

The reef limestone does not extend along the entire length of the cliff At about 500 feet from the eastern end of the cliff it grades into calcareous sandstone with shelly fossils which for some distance from the edge of the reef limestone contains some coral boulders, obviously derived from the old reef (fig 3)

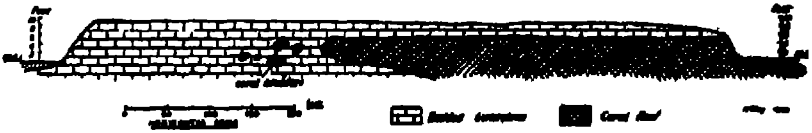

Fig 3—Section of limestone cliff with fossil coral reef at Salmon Bay

OTHER MARINE LIMESTONES

Marine fossiliferous limestones or calcareous sandstones are found in some places but their relationship with the dune limestones is not always clear In the western half of Geordie Bay there are limestones with *Katelysia, Cardium* and *Polinices* to a height of 1½ 2 feet above H W L In Thompson Bay about 100 yards west of the main jetty fossiliferous limestones mainly containing *Katelysia*, rise from L W L inshore to a height somewhat above H W L However in neither place can the relationships of these rocks with the dune limestones be established Away from the shore solid limestone with pelecypods occurs 8 9 feet above H W L on the east side of the spur separating Government House Lake from Serpentine Lake and a narrow ridge of shell limestone rising to about 5 feet above H W L, separates Parkbury s Flat from the eastern arm of Lake Bagdad From their general occurrence it is likely that these two deposits form part of the Coastal Limestone Series and are older than the surrounding dune limestones

Elsewhere limestones largely made up of shell grit are met with at or slightly above H W L *e g* along the shores of Wilson Bay

DUNE LIMESTONES

Dune limestones make up the bulk of Rottnest Island Since limestones of this type have a wide distribution along the coasts of Western Australia and have been discussed by me in two recent publications (1947 a and b) little need be said about them here Characteristic outcrops can be seen everywhere on the island A particularly instructive and easily accessible section may be studied at Bathurst Point at the north western end of Thompson Bay Certain layers of the limestone are here penetrated by root structures" generally calcareous secondary fillings of cavities left by the decay of roots of ancient vegetation—a characteristic feature of these dune limestones in all parts of Western Australia Such root structures may be seen in other parts of the island, *e g*, at Strickland Bay at Vera Rock and at Salmon Point and in some places the layers containing them may be seen to disappear below sea level

Another interesting feature of the section at Bathurst Point is the existence of two generations of dune limestones. Just north of the lighthouse a lower cross-bedded grey limestone is separated from an upper, whitish, friable limestone, dipping 25° S., by a somewhat irregular hardened layer which in every respect resembles the travertine crust which is now found on the surface of many dune limestones on the mainland. Apparently sufficient time elapsed between the formation of the two dune limestones at Bathurst Point to allow a travertine crust to develop on the earlier dune, before it was buried by the second.

Very similar conditions can be observed at Vera Rock, on the south coast. A feature which adds to the interest of this locality is the covering of recent blown calcareous sand with partly travertine-encrusted roots of living trees, demonstrating a dune limestone with root structures *in statu nascendi*.

In general the dune limestones are characterized by the prevalence of steeply dipping ("foreset") beds, mostly dipping at 20° to 25° in various directions. In many places such steeply dipping beds are found down to and below L.W.L.

The dune limestones are uniformly fine grained rocks, consisting mostly of fragments of shells and other organic remains, with a varying admixture of quartz grains. Occasionally, however, coarser shell grit and larger quartz grains were blown up high. An interesting patch of such material was found about 60 feet above S.L. on a hill east of Mt. Herschell.

AGE AND CORRELATION OF THE COASTAL LIMESTONE

The geological section at Salmon Bay is of considerable interest because it resembles closely the section of the older limestones of the Abrolhos Islands, 300 miles farther north (Teichert 1947a). The major islands of this group are characterized by a foundation of solid reef limestone, overlain by on the average about 3 feet of non-coralline limestone, containing a shelly fossil fauna. The tops of these shell limestone platforms are as a rule situated about 10 feet above H.W.L., that is, at the same height as the top of the non-coralline limestone in the Salmon Bay cliff. A small coral reef on the mainland coast at Dongarra, 30 miles south of Geraldton, occupies a very similar position (Teichert 1947a), and it seems an obvious conclusion that the older reef limestones of the Abrolhos Islands, the Dongarra reef, and the Salmon Bay reef of Rottnest Island are all of the same age. I have previously suggested that they were formed during an interglacial period of the Pleistocene, when the sea-level stood higher than now and the climate was possibly slightly warmer. Reef building corals, including a vigorous growth of *Acropora*, then found a favourable environment 300 miles south of the present southern limit of the coral reef belt.

Even to-day a fairly vigorous growth of reef corals is found in a few places around Rottnest Island. In the tidal zone near Cape Vlaming there are many healthy colonies of *Pocillopora*, and *Siderastraea radians* also occurs there. Numerous patches of vividly coloured *Pocillopora* colonies can be seen in the vicinity of Cape Parker and, no doubt, they must occur elsewhere along the coasts of the island. On the beach near Parker Point I found a bleached, though very fresh-looking specimen of *Platygyra* ("*Meandrina*") *lamellina* which makes it seem likely that this typical reef coral still survives in the waters around Rottnest.

The stratigraphical position of the dune limestones of Rottnest Island corresponds to that of the dune limestones of the Abrolhos Islands and of the mainland of Western Australia. Observations on Rottnest Island strongly suggest that the dune limestones were deposited at a time when the water level stood lower than now, for almost everywhere they can be seen to extend below L.W.L. and they are now being vigorously attacked by marine erosion. Age and correlation of these rocks have been discussed more fully elsewhere (1947 a and b): they were regarded as formations of one of the later glacial stages, probably the last, of the Pleistocene, built up at a time when much of the limestone-covered continental shelf was exposed above sea-level and thus furnished material for extensive dune formations along a thousand-mile stretch of mainland coast. Dunes were thus accumulated on the promontory formed by the 10-fathom line and elsewhere on the continental shelf.

The Shell Deposits of the Lake Area

The shores of the salt lakes are lined with fossiliferous rocks and loose deposits in which shells of pelecypods and gastropods predominate, in most places to such an extent that we may speak of "shell deposits" or "coquina beds." Almost any point on the lake shores is equally well suited for the study of these formations, although they are better developed in some places than in others. Along certain shores they form but a narrow fringe, as, *e.g.*, on the north coasts of Lakes Bagdad and Herschell. Elsewhere, for example, east of Lake Bagdad and along the south side of Serpentine Lake, they form wider belts. Also, a low flat area north of Garden Lake, almost extending as far as the sea to the north and separated from the "Basin" only by a narrow ridge of dune limestone, is entirely covered with deposits of the same kind. East of Government House Lake is another large flat area, part of which is used as an aerodrome, extending as far and beyond Bickley Swamp; this flat is also covered with shell deposits, though of a somewhat different type.

Whereas everywhere else the shell beds are surrounded by dune limestone ridges, towards the north-east, between Government House Lake and Thompson Bay they are covered by more recent, loose sand dunes which form a narrow belt along the coast between a point somewhat N.W. of the old Government House and the vicinity of Philip Point. Strongly eroded dune limestone crops out on the coast a short distance west of the Point.

Along the lake shores the shell deposits are cemented into limestone, apparently because here they are alternately submerged and exposed with the changing seasons. In summer the lake level falls and exposes a fringe or platform of fossiliferous limestone from which large collections can be made. The position of this platform, as mentioned earlier, is approximately at, or perhaps slightly higher than M.S.L. The lakes are, of course, now quite devoid of molluscan life, the salinity exceeding 10% in the summer.

Away from the lake shores the deposits are uncemented and rise to varying heights. They were found in the highest position on a small flat in the eastern continuation of Lake Bagdad, just south-west of Mount Herschell. From the limestone platform on the lake shore the ground rises gradually to a terrace about 9 feet high (approximately 6-7 feet above H.W.L.S.) which consists entirely of densely packed shells, mostly rather large forms such as *Marcia, Katelysia, Bullaria, Polinices,* but also *Peronidella* and regular echinoids. From this terrace shell beds rise further to a height of 12½ feet (about 10 feet above H.W.L.S.), but these higher deposits consist of shell grit and small shells, mostly gastropods of the *Coxiella* type. This is the highest point at which such deposits have been found.

On Padbury's Flat, north of Lake Bagdad, loose shell deposits were found up to a height of 5 ft. 3 in. above the lake shore platform (about 3 feet above H.W.L.S.). On the north-east side of Government House Lake, south-east of View Hill, there are distinct beach ridges of loose shell material, but their height was not measured. Finally, the surface of the flat east of Government House Lake is 6 ft. 3 in. above the lake shore platform (8 to 9 feet above L.W.L.S.)

As to the composition of the coquina deposits in various parts of the island, no close analysis has as yet been made. Reath, in 1925, listed the following molluscan species from "sub-recent" deposits on Rottnest Island:

PELECYPODA.—*Brachyodontes erosus* Lam., *Cardita* sp. *Dosinia lucinalis* Lam., *Marcia peronii* Lam., *Veneruplis planicosta* Desh., *Amphidesma praecisa* Reeve, *Nausitoria saulii* Wright.

GASTROPODA.—*Cantharidus nitens* Kiener, *Patelloidea connoidea* Quay and Gainard, *Bembicium melanostoma, Bittium estuarium* Tate, *Tonna variegata* Ten. Woods, *Arcularia victoriana* Iredale, *A. rufula* Kiener.

It is probable that most, if not all, of these come from the shell deposits of the salt lake area, though even a preliminary survey of the shell deposits shows that the list must be rather incomplete[*]. However, I am not in a position to make many additions, but other forces noticed included *Ostrea, Chama, Vermetus,* and *Turbo.*

Besides the shelly fauna, echinoids are commonly found, particularly fragments of the large irregular genus *Peronidella.* In the vicinity of the bathing jetty on the shore of Government House Lake there is a large colony of *Favites* embedded in the limestone—the only fossil coral seen on the island outside the Salmon Bay coral reef.

The greatest variety of species is as a rule found in the immediate vicinity of the present lakes and up to a few feet above the lake shore platform. The highest deposits seem to have an impoverished fauna. It has already been mentioned that the deposits at heights between 9 and 12½ feet east of Lake Bagdad consist largely of *Coxiella.* Similarly, the deposits east of Government House Lake may be described as shell sand in which *Coxiella* is common, although there is a fair admixture of pelecypod shells, chiefly *Katelysia.* In the eastern extension of this flat is Bickley Swamp which is underlain by a marly deposit containing some *Coxiella* shells.

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[*] It must be remembered that the collections studied by Reath came from several deposits of different ages. Some came from beds definitely older than the dune limestones (Peppermint Grove, Minim Cove) and therefore of Pleistocene age.

Marine Benches and Other Erosion Marks

Perhaps the most striking features of Rottnest Island are the many signs of marine erosion at various heights above sea-level, found in many parts of the outer coast, but more particularly around the shores of the salt lakes. It is easily possible to distinguish three levels of marine erosion which may be known as "high," "intermediate," and "low" respectively, although in a few cases certain erosional or other features cannot be correlated with certainty with any of these levels.

One of the localities where all three erosion levels may be observd in most perfect preservation is on the north shore of Government House Lake, close to the Causeway (fig. 4; pl. V, fig. 2). Here dune limestone with south-east dipping stratification is exposed in a cliff which forms an overhanging ledge several feet wide. This ledge is perfectly flat, carved out of the limestone, and is situated about 8 ft 9 in. above the limestone platform surrounding the lake, or about 11 feet above L.W.L. Below this ledge there is a well-marked erosion notch the base of which is 4 ft. 6 in. below the level of the platform. Farther down near the foot of the cliff the limestone is much more strongly eroded by a deeply incised notch, the base of which is 2 ft. 6 in. below the base of the upper notch and about 1 ft. 9 in. above the lake shore platform. This platform is situated at or perhaps slightly above mean sea-level.

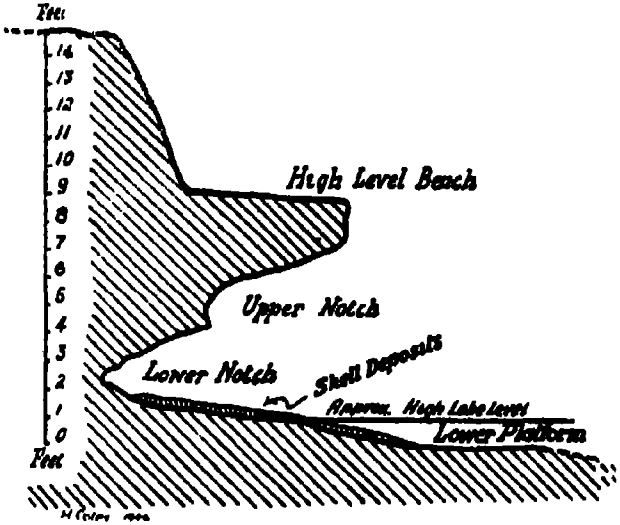

Fig 4.—Profile of shore cliff, Government House Lake, near Causeway.

A similar cliff profile, although not often so well developed, may be seen elsewhere along the lake shores, for example on some small islets between Lakes Bagdad and Herschell, and on the north side of Serpentine Lake.

The characteristics of these three erosion levels may be amplified by some further observations:

HIGH LEVEL BENCH.—This characteristic feature is preserved in many parts of the island along the outer coast as well as along the lake shores and has already been briefly referred to in publications by Somerville (1921) and by Clarke (1926). It is no doubt the remnant of a normal shore platform (Pl. VI, figs 1, 2). Along the outer coast its surface is at about 10 feet above present L.W.L. and along the lakes it is 8 to 9 feet above the lake shore platform, or about 10 to 11 feet above L.W.L. The bench is particularly well preserved in the vicinity of Cape Vlaming, in Wilson Bay, in various places along Strickland Bay and between North Point and Armstrong Point, but also in many other places along the outer coast. In the lake area it shows up well along the north shore of Serpentine Lake, on the south side of Lake Herschell and around the shores of the eastern arm of Lake Bagdad. It is generally cut into cross-bedded or steeply dipping dune limestones and differential erosion plays no part in its formation.

Associated with this level are probably the highest shell deposits mentioned above, especially those rising to 12½ feet above the lake shore platform in the eastern extension of Lake Bagdad.

INTERMEDIATE LEVEL.—In the cliff near the Causeway, this level is represented by the "upper notch," about 4 feet above that of the lake shore platform. Except near the Causeway this level is particularly well preserved between Lakes Bagdad and Herschell and indications of it may be seen elsewhere In some places, however, no traces of it can be detected as, *e g.*, along the south shore of Lake Bagdad The shallowness of this notch together with its erratic distribution around the lakes suggests that the sea did not remain long at the level at which the notch was cut Owing to the small size of the lakes wave erosion must be rather ineffective and the upper as well as the lower notch may be regarded as essentially due to solution.

Associated with the upper notch level are probably many of the shell deposits, for example, those of the flat ("aerodrome") east of Government House Lake which rises to about 6 feet above the lake shore platform. The shell beds of Padbury's Flat and the lower coquina deposits east of Lake Bagdad are found at about the same height and probably the shell sand ridges on the north coast of Government House Lake, south-east of View Hill, also belong here

Along the outer coast, as may indeed be expected, most traces of this erosion level have been obliterated. However, in a particularly sheltered place in the north-east corner of Thompson Bay there are remnants of a fossiliferous conglomerate adhering to the cliff at a height of about 4½ feet above M.S.L. which corresponds approximately to the position of the upper notch in the shore cliff profile of the lakes

On the west side of Wilson Bay there is a marked bench situated at about H.W.L.S. This seems to be the vestige of a normal shore platform made by the same sea which was responsible for the upper notch of the lake cliffs.

LOW LEVEL.—This is represented by the lower notch in the lake shore profile which is well preserved in a great many places. Next to the high level bench it is the most characteristic feature of the lake shores. Its position is between 1 and 2 feet above highest lake level. Its exact position relative to sea-level (M.S.L. or Datum) could only be established by an instrumental survey, but indications are that this notch is in a position corresponding to present H.W.L. and probably about 2½ feet higher than the erosion notch produced by the action of the sea at present mean sea-level around the outer coast of the island.

This notch, too, must be a solution feature. It is in places several feet deep, although the destructive power of the waves of these small lakes must be negligible.

Features associated with this lower notch are the lowest shell deposits and the limestone platform surrounding the lake shores. This is an erosion platform truncating dune limestones as is well seen on the north side of Government House Lake, near the Causeway. It is dry in normal summers, when the lake level falls. In most places the platform is covered with more recently cemented calcareous sand and shell grit containing many shelly and other fossils as described above. On the narrow shelf between Lakes Bagdad and Herschell an interesting "edgewise conglomerate" can be seen formed of broken-up thin laminae of dune limestone.

No traces of this erosion level have been preserved anywhere along the outer coast.

Information regarding former positions of sea-level may be summed up in the following table:

TABLE 1. FEATURES CAUSALLY CONNECTED WITH :—

High-water Level	*Height above H.W.L.*	*Mean-Water Level*	*Height above M.W.L.*	*Low Water Level*	*Height above L.W.L.*
Highest shell beds east of Lake Bagdad.	10 ft.			Upper platform of outer coast and around salt lakes.	10-11 ft.
Intermediate shell beds (partly associated with lower levels).	3-4 ft.	Upper notch of salt lake cliffs.	4-5 ft.	High-water level bench in Wilson's Bay.	5 ft.
		Fossiliferous conglomerate, N.W. corner of Thompson Bay.	abt. 5 ft.		
		Lower notch of salt lake cliffs.	abt. 2 ft.	Lakeshore platform and lowest shell deposits.	2-3 ft.

On the mainland along the Swan and Helena Rivers Aurousseau and Budge (1921) established the presence of three erosion cycles, called Guildford, West Midland and Helena, each initiated by a eustatic lowering of sea-level. From Aurousseau and Budge's data it would appear that the sea-level stands were as follows:

pre-Guildford	22 ft. above present.
pre-West Midland	14 „ „ „
pre-Helena	7 „ „ „

While there is no evidence on Rottnest Island of the pre-Guildford stand, the pre-West Midland stand is represented by the high-level platforms, as indeed already suggested by Aurousseau and Budge, although as we have seen sea-level might have been somewhat lower than indicated by those authors. The shell beds and undercut cliffs are correlated by Aurousseau and Budge with the Helena cycle, although they do not mention the existence of a double notch nor the presence of shell beds at greatly varying heights. It would seem then that the pre-Helena stand corresponds to our intermediate level on Rottnest and is responsible for the upper notch of the lake shores and associated features.

Evidence of the lowest 2 ft. stand has yet to be discovered on the mainland.

Outline of Geological History

The oldest rocks of Rottnest Island are probably the coral reef limestone of Salmon Bay and associated rocks, dating back to one of the interglacial periods of the Pleistocene. Limestone forms the foundation of the island down to a depth of 200 feet below sea-level, but the nature of these rocks is not known in detail. At the time of the formation of the Salmon Bay reef sea-level stood at least 8 feet above the present, although it is, of course, entirely possible that the reef stood originally higher and was subsequently denuded to its present level. Owing to some change in water level or temperature or both, coral growth was then interrupted and non-coralline limestone was deposited on the eroded surface of the coral reef.

Subsequently sea-level must have fallen and the old limestone foundation greatly eroded and denuded and calcareous dunes were swept together on top and around the erosion remnants. At that time much of the shelf surrounding the present island must have been dry land, supplying material for the large dune formations which could hardly have been accumulated under present-day conditions. It is also evident that in many places these old dunes were deposited and covered with vegetation in a position below present sea-level.

The dunes were heaped up in an irregular manner into ridges and hummocks of different heights. No doubt the dune topography extends below sea-level in the vicinity of the island and the many reefs near its coasts are but the tops of submerged and partly destroyed limestone dunes. A group of dunes in the south remained separated from a dune ridge in the north by a series of depressions, now reaching 30 feet below sea-level and occupied by salt lakes.

In general it may be concluded that the dunes were built up on a platform the approximate outline of which is now indicated by the 5-fathom line, because inside this line the sea floor is very irregular, but beyond it the bottom slopes away gradually to the 10-fathom line and farther (fig. 5). Also, 5 fathoms is the maximum depth of Government House Lake. Other lakes may have similar depths.

After the deposition and cementation of the dune limestones the sea rose to about 10 feet above its present level and from general evidence elsewhere in Western Australia (Teichert 1947a) there is reason to suppose that this rise was part of the general eustatic upward movement of sea-level after the end of the Pleistocene. The group of calcareous dunes, now hardened into dune limestones, became an island, and the dune valleys described above were converted into a deep and ramified inlet of the sea. With its entrance facing landward and away from the direction of the prevailing winds, this inlet was in an extremely sheltered position and offered favourable living con-deposited at a time when sea-level stood up to 20-25 feet higher than now. This corresponds well with Zeuner's Late Monasterian level for which ample evidence seems to exist in the Mediterranean, in western Europe, and elsewhere (Zeuner, 1945, p. 249). This was the lowest of all the interglacial sea-levels of the Pleistocene and belongs, according to Zeuner, to the last interglacial period (Riss-Würm). The time was about 125,000 years ago.

The dune limestones would have been formed at the time of eustatic regression during the ensuing last glacial ice-age (Würm). This conclusion seems entirely acceptable in the light of the Western Australian evidence.

(2) The geological evidence for this "Late Monasterian" level may easily overlap with or be camouflaged by the evidence for the post-glacial, early Recent, eustatic rise in sea-level of which, as we have seen, there is also ample evidence in Western Australia. During this time platforms were carved into the late glacial dune limestones and loose shells deposits were heaped up. This coincidence of the last interglacial and the early post-glacial sea-levels is a factor which probably deserves the greatest attention.

From evidence in many parts of the world, including the Abrolhos Islands, it has been concluded, as indeed first suggested by Daly, that the post-glacial rise of sea-level was of the order of 15 or 20 feet, but no signs of a sea-level higher than 10 or 11 feet have been detected on Rottnest Island No explanation of this fact can be offered at this stage.

As regards the lowering of sea-level after the high stand in early Recent times it is necessary to call attention to some discrepancies in the evidence from Rottnest Island and from the Abrolhos Islands. From the mode of arrangement and preservation of the younger coral shingle beach ridges on some of the Abrolhos Islands I had been inclined to conclude (1947a) that the mid-Recent and later subsidence of sea-level took place gradually and continuously during the last 2,000 years or so and has now come to an end. On Rottnest Island as we have seen there is evidence of a lowering of sea-level by three steps, separated by two stillstand periods which have left their unmistakable traces in the cliffs Further light on this problem can only be thrown by a more systematic investigation of the mainland coast of Western Australia between Cape Leeuwin and Geraldton.

Recent subsidence of sea-level by steps rather than as a gradual phenomenon has been advocated by several modern writers. In the Pacific Stearns (1941, 1945) recognized evidence for a "five-foot stand" and a "twenty-five-foot stand" of the sea. In the Great Barrier Reef Steers (1937) proved the existence of a "lower bench" indicating a recent 5-foot negative movement of sea-level. In the East Indies Kuenen (1933) found benches at 5-6½ feet and at 1½-3 feet above "mean water level." The lower one of these benches is probably to be correlated with our lower notch of the lake shore profile of Rottnest Island.

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Figure 1

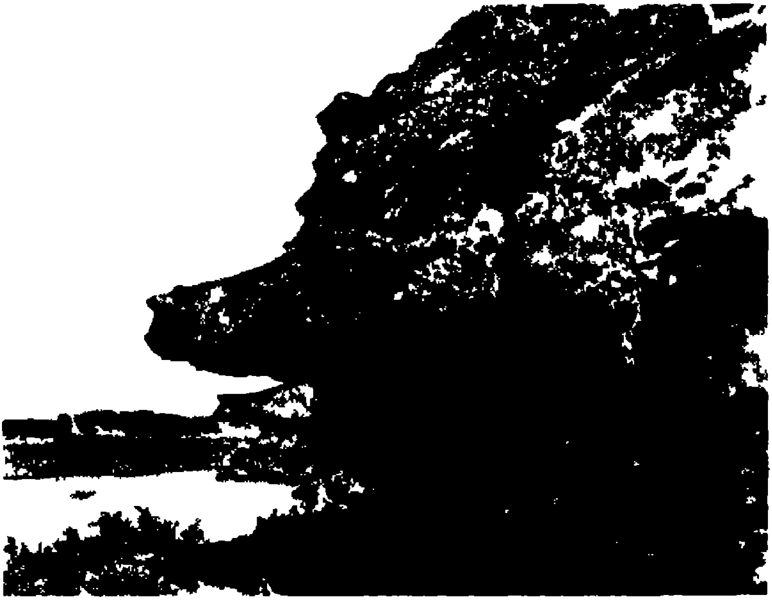

Figure 2

Figure 1

Figure 2

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Explanation of Plates

PLATE V

Fig. 1 —Emerged coral reef with overlying bedded limestone Salmon Bay

Fig 2 —Shore cliff Government House Lake at Causeway showing high level bench upper notch and lower notch carved out of a uniformly dipping series of dune limestone

PLATE VI

Fig 1.—High level platform on outer coast west of North Point

Fig 2 —Narrow ledge remnant of high level platform in Wilson Bay

7—A Study of the Palaeozoic Genus Hercynella, with Description of Three Species from the Yeringian (Lower Devonian) of Victoria.

By EDMUND D. GILL, B.A., B.D.

[Read 12th December, 1946]

Abstract

Hercynella is a primitive gasteropod which has previously been classified as a pulmonate Evidence is put forward which suggests that it is a normal marine gasteropod and not a pulmonate. This evidence deals with its analogies with other fossil forms, its ecology, and the palaeontological history of pulmonates Three species, including two new ones, are described.

Taxonomy

The classification of the genus *Hercynella* is most difficult, and can never be fully objective, because of the lack of structures in the exoskeleton to provide clues of what the animal was like. Apparent genetic relationships as indicated by analogy, and ecological considerations, are the only guides in its classification.

HISTORY OF THE GENUS

Emanuel Kayser erected the genus in 1878; its species range from Middle Silurian to Middle Devonian. Barrande studied shells of this type, but believing them to be very like the extant genus *Pilidium* Forbes, used the generic name *Pilidion* in his manuscript. Kayser was of the opinion that Barrande was mistaken in referring his asymmetric shells to the above genus of extant symmetric gasteropods, and proposed the name *Hercynella*. Perner pointed out that *Pilidion* latinized becomes *Pilidium* and so should be rejected as a junior homonym; Knight has shown that in any case the name was already occupied.

O'Connell (1914, p. 94) claimed that "since the species *bohemica* was the type of Barrande's genus, it remains the type of *Hercynella*." This is apparently a reference to the description of *H. bohemica* as genotype in Perner (1911, p. 270). However, Cossmann had already defined *H. beyrichi* as genotype (1878, p. 142). Knight (1941, p. 146) has brought together information on the genotype of *Hercynella* as follows:

"GENOTYPE, by subsequent designation of Cossmann, 1895 (p. 142) *Hercynella beyrichi* Kayser, 1878.

OBJECTIVE SYNONYMS:

1. *Pilidium* Kayser, 1878 (p. 101), a homonym of *Pilidium* Müller 1846, Forbes 1849, and Middendorf, 1851. Genotype, by objective synonymy, *Hercynella beyrichi* Kayser, 1878.
2. *Pilidion* Perner, 1911 (p. 270), a homonym of *Pilidion* Wagler, 1830. Genotype, by objective synonymy, *Hercynella beyrichi* Kayser, 1878."

NATURE OF EXOSKELETON

Most living gasteropods have an exoskeleton which consists of a horny periostracum, under which are two layers of calcium carbonate (outer layer calcite; inner one aragonite). The periostracum is seldom preserved on fossils. Many *Hercynella* shells are exceedingly thin, e.g., *H. killarensis* (0.25 to 0.55 mm. thick), and if they were composed of calcium carbonate alone, they would have been practically useless as organs of support or protection. To have strength at all, it must have possessed, one imagines, a strong periostracum of some kind. The amount of calcium carbonate apparently varied from species to species, as some of the Bohemian forms, for example, had quite thick shells.

Surface features of the exoskeleton (generally called "ornament," a term which does not express the scientific conception of these structures) consist of (a) radial lines or folds, and/or (b) concentric lines or folds. The concentric structures may be regarded as an hypertrophy of growth line structures. In most cases the characteristic fold of the genus may be interpreted as an hypertrophy of a radial plica. but in some cases it is curved without relation to the ornament. Knight (1941, p. 147), says that the fold may be on either the left or the right side, an interesting point from the point of view of genetics.

The tendencies towards radial and concentric ornament are developed to varying degrees in the species described in this paper. *H. victoriae* has a radial ornament of very narrow folds or plicae, about one millimetre wide at the margin of mature shells. They are plicae and not costae, because they involve the whole thickness of the shell, appearing on the steinkern as well as in the external mould.

H. killarensis has concentric undulations superimposed on which are radial ribs and concentric lirae.

H. petasoida has narrow concentric undulations and growth lines with very faint and fine radial lirae.

ORIENTATION

There is no way of determining for certain which is the anterior and which the posterior end of the shell, in *Hercynella*, because of the lack of muscle scars, etc. Analogy is the only aid. The patelliform and coniform shells described in Knight's (1941) monograph on "Paleozoic Gasteropod Genotypes" were listed, and it was found that the orientation of only seven of some 21 forms was known for certain. It was noted that in all cases except *Halophiala* (whose apex is sub-central), there is a displacement of the apex towards one end or the other, and any inclination of the apex or commencement of enrolment is in that same direction. In the seven genera whose orientation is known, the apex of five is displaced anteriorly, and of two posteriorly. Genera of similar form in Davies' (1935) "Tertiary Faunas" were then listed and seven were noted to have a displacement of the apex (*Helcion* and *Acmaea* were treated as the same genus for the present purpose, as their shells cannot be distinguished). In these it was noted that the apex is displaced posteriorly in five genera, and anteriorly in two—the opposite from the palaeozoic genera! A special study would be necessary to determine to what extent these figures are significant, but the following points are worth making:

(a) The number of palaeozoic patelloid genera is much greater, which is to be expected in view of the fact that the cone is the original fundamental shape of the gasteropod exoskeleton. Davies suggests (1935, p. 209), that all the extant patelliform shells have been secondarily developed from more usual forms.

(b) That the displacement of the apex is the reversal in most genera, in the Tertiary, from that which occurs in most palaeozoic genera is interesting in view of gasteropod torsion, but the point needs further investigation anatomically and ontogenetically.

It would appear that as the majority of palaeozoic patelloid genera have their apices displaced anteriorly, the end of *Hercynella* towards which the apex is displaced, should, for the sake of description, be regarded as the anterior end.

Ontogeny and Evolution

Typical gasteropods develop a shell in the advanced larval stage, which, no doubt, acts as a protective organ. It is essentially a cap or cone which enlarges as the animal grows, i.e., as the membrane secreting the shell enlarges, it produces a larger shell section. The original cap or protoconch widens as it grows and results in the cone shape. This fundamental cone shape is modified in every conceivable way; every stage is present between a slightly inclined apex and a fully enrolled shell. The enrolment may be in the same plane, giving a euomphaloid shell; or it may circle an imaginary axis to give anything from a low spire to a *Turritella* type. Sometimes the cone is coiled loosely and sometimes tightly. All manner of variations in so-called ornament are also to be found. These features were apparently all governed by genes, as they were inherited from generation to generation.

Now just as *Lingula* among the brachiopods has maintained the simple brachiopod exoskeleton (a dorsal plate and a ventral plate), throughout almost the whole of the palaeontological sequence, so there is a succession of gasteropods which have maintained the simple conoid gasteropod shell. *Hercynella* is a Silurian and Devonian genus which possesses a cone-like exoskeleton, not far from the gasteropod prototype (see Borradaile *et auctt.*, 1935, p. 544). It has an erect apex as a rule, but the cone is modified by a radial ridge and/or sinus. Its later ontogeny is portrayed in a series of growth lines which indicate that it began as a minute cone which enlarged as the animal grew. The embryonic shell or nucleus apparently consisted of a micromorph of the adult shell.

If the fundamental form of the exoskeleton of gasteropods is a cone, then it is to be expected that the earliest gasteropods would conform to this pattern. Cambrian genera such as *Helcionella*, *Hypseloconus*, *Metoptoma*, *Palaeacmaea*, *Parmorphella*, *Proplina*, *Scenella*, and *Tryblidium* are all patelliform or coniform shells. A succession of similar forms can be traced through the various geological periods, although the genetic relationships of these genera have not yet been fully determined. However, the relationship of *Hercynella* to other genera will now be discussed.

Genetic Relationships

Symmetry is a major concept in zoology. The prototype gasteropod exoskeleton was apparently a symmetrical cone, but modifications of the cone lead commonly from a radial to a bilateral symmetry. The genus *Hercynella* comprises a group of species which are strangely asymmetrical, chiefly because of an eccentric apex and a curious fold and/or sinus characteristic of the genus. Apparent evidence of a previous bilateral symmetry is seen in an early form like *H. patelliformis* (from the Bertie Waterlime), whose apex is not far from the centre, whose outline is regular and not far from the circular, and which has no sharp sinus or elevated fold, but simply a slight inward flexure.

Early workers were by no means certain as to what the relationships of *Hercynella* were. Fischer put the genus in the family Fissurellidae, but commented that it was impossible at the time to classify *Hercynella*. Kayser compared *Hercynella* with the Patellidae and Capulidae, while Perner provided support for a comparison of the genus with the Tertiary gasteropod *Valenciennesia*, a pulmonate which has a very definite groove on the left side accommodating a respiratory tube (see Davies, 1935). Subsequent writers seem to have accepted this hypothesis without re-examination, and looked upon the fold in the shell of *Hercynella* as homologous with the pulmonary groove of *Valenciennesia*. But the fold may, in reality, have no such biological significance, because:

(a) In *H. patelliformis* the "fold" is but a very shallow sinus almost on the longitudinal axis of the shell.

(b) In *H. victoriae* it is a simple fold in the shell with a concave flexure on each side, sharper on one side than the other.

(c) In *H. petasoida* there is a fairly sharp fold and a sharp sinus but they are not contiguous.

(d) In *H. beyrichi*, the genotype, there is a sharp curved fold.

(e) *H. bohemica* has a curved fold, but it is not a raised convex feature, but rather the surface of the shell dropping in and continuing at a lower level.

(f) In some specimens of *H. nobilis*, there are two folds almost opposite each other (Perner, pls. 47 and 49).

(g) In the young specimens of some species (e.g., *H. bohemica*), the fold is almost indiscernible.

(h) In *H petasoida* and *H killarensis*, spp. nov., the shell is modified by both a fold and a sinus.

There are a large number of variations, and, in some species, the structure may appear on either the left or the right side of the median axis. It is apparent from this brief description of the variations in *Hercynella* that there is no clear homology between the fold in the shell of this genus and the well-defined, consistently-placed respiratory groove of *Valenciennesia*.

Further, there is reason to believe that the genetic relationships of *Hercynella* are with contemporary fully marine gasteropods rather than with the Tertiary genus *Valenciennesia*. *Hercynella* ranges from Middle Silurian to Middle Devonian, but appears to have reached its acme in the Lower Devonian. Contemporary genera possessing a similar type of exoskeleton are *Calloconus*, *Orthonychia*, and *Procrucibulum*. *Calloconus* Perner (genotype from the Lower Devonian of Bohemia), is a gasteropod with coniform shell, eccentric apex tilted slightly anteriorly(?), outline of aperture broadly sub-elliptical, and shell thick with concentric undulations; there is no fold or sinus as in *Hercynella*. However, *Hercynella killarensis* sp. nov., has an eccentric apex tilted anteriorly and concentric undulations. *Orthonychia* Hall has a shell in the form of a high cone (horn-shaped), with inclined, but not coiled, apex in the simpler form (e.g., the genotype), but having radial folds and some other modifications in other species. The genotype comes from the Lower Devonian of United States of America. *Procrucibulum* Perner (genotype from Bohemian Lower Devonian), is a gasteropod with a patelliform exoskeleton having a slightly twisted apex, and a low sharp ridge rising in the apex inside the shell and passing clockwise in a very gentle spiral, conformable to the twist of the shell, but dying out before reaching the margin. It is to be noted that this is not the coiling of a cone or tube as in a typical gasteropod; but, rather, a twist in the cone itself, reflecting a twisting of the visceral hump—a most interesting fact in view of gasteropod torsion.

It would appear, then, that in the genera *Calloconus*, *Orthonychia*, *Procrucibulum*, and *Hercynella*, we have four related variants of the primitive gasteropod cone, the nearest to which in known fossils is *Palaeacmaea*, whose genotype comes from the Cambrian and whose species stretch into the Ordovician and may be Silurian.

The *Calloconus* exoskeleton presents a bilateral symmetry, having lost the original radial symmetry by having an aperture with a sub-elliptical in place of a circular outline, and also an apex inclined (?) anteriorly; this is the first stage in the enrolment of the gasteropod cone. *Orthonychia* has this same commencement of coiling, and some species have radial folds in the shell.

Procrucibulum modifies the simple conoid exoskeleton by being slightly asymmetric and having a twist or torsion. *Hercynella* possesses typically an asymmetric apex, and is made still more asymmetrical by a radial ridge and/or sinus, which occurs on one side or other of the longitudinal axis.

The foregoing facts suggest that *Palaeacmaea*, *Calloconus*, *Orthonychia*, *Procrucibulum*, and *Hercynella* are, in some way, genetically related. But the last-named genus has hitherto been classified as a pulmonate. I am of the opinion that *Hercynella* is a fully marine gasteropod and not a pulmonate. This hypothesis is based upon its apparent genetic relationships as discussed above; its ecology; and the palaeontological history of pulmonates.

Palaeoecology of *Hercynella*

The genotype of *Hercynella* is derived from the Hercynian fauna of the Harz, which is partly Rhenish and partly Bohemian in its facies. As far as the author is aware, *Hercynella* has not been found in beds of purely Rhenish facies. The largest *Hercynella* fauna in both species and numbers, comes from Bohemia, from whence also, it is interesting to note, come the genotypes of *Calloconus* and *Procrucibulum*. The facies of these beds is indisputably marine off-shore. The only way in which a pulmonate gasteropod could occur in these beds would be for it to have been transported there from the shore (if an air-breather), or from shallow waters (if a secondary pulmonate), by ocean currents. If this were the case, the shell would show signs of the wear and tear of transport. Moreover, one would not expect to find many individuals present, as it would only be an occasional shell which would be so transported. As far as can be discovered from the literature, there are no signs of current bedding in these strata, the shells do not show the wear and tear of transport, and the individuals are numerous, there being present fifteen species, some in comparatively large numbers.

This evidence of the facies of *Hercynella* is well supported by the results of a study of the facies of the Lower Devonian fauna of Killara, Victoria, from which the species described in this paper were derived. At Killara, three facies can be distinguished:

(a) A near-shore facies, the rocks consisting of quartzites and sandstones.

(b) An off-shore facies, the rocks consisting of mudstones and very fine sandstones (they look like mudstones, but grit on the teeth).

(c) A pelagic facies, the rocks consisting of thinly-bedded mudstones (some white), with a pelagic fauna including very numerous minute *Styliolina fissurella*.

It is in the second, the off-shore facies, that the species of *Hercynella* described in this paper have been found. The fauna (so far as it has been worked out), consists of the following:

TRILOBITA

Acanthopyge australis (McCoy)
Calymene bowiei Gill
C. killarensis Gill
Gravicalymene sp.
Odontochile sp.
Odontopleura sp.
Phacops aff. *fecundus* Barrande
Phacops sp.

BRACHIOPODA

Acrospirifer (?) *lilydalensis* (Chapman)
Anoplia australis Gill
A withersi Gill
Chonetes bowneae Gill
C robusta Chapman
C. psilophia Gill
C. killarensis Gill
Dalmanella aff. *elegantula* (Dalman)
Fascicostella gervillei Defrance
Hipparionyx minor Clarke
Leptaena rhomboidalis (Wilckens)
Nucleospira australis McCoy
Plectodonta bipartita (Chapman)

PELECYPODA

Conocardium bellulum (Cresswell)
Ctenodonta portlocki Chapman
Cypricardinia contexta Barrande
Mytilarca acutirostris Chapman

Nucula lamellata Hall
Nuculites maccoyianus Chapman
Nuculoidea opima australis (Chapman)
Tancrediopsis raricostae (Chapman)

GASTEROPODA
"*Bellerophon fasciatus* Lindstrom"
Euomphalus centrifugalis Chapman
Hercynella killarensis, sp. nov.
H. petasoida, sp. nov.
H victoriae Chapman
"*Pleurotomaria*" *maccoyi* Chapman
Scalaetrochus antiquus (Cresswell)

OSTRACODA
Beyrichia cf *kloedeni* McCoy
B ligatura Chapman
B maccoyiana australiae Chapman
B. wooriyallockensis Chapman

ANTHOZOA
"*Lindstroemia*" *ampla* Chapman
"*L*" *yeringae* Chapman
Pleurodictyum megastomum Dun

OTHER ANIMALIA
Conularia chapmani Fletcher
Fenestrellina margaritifera (Chapman)
Undet orthoceracones

PLANTAE
Hedeia corymbosa Cookson

Of the above list (covering fossil localities 33, 34, and 35—see Gill, 1945, pp. 179, 183-184), the trilobites and brachiopods have been critically studied, but not the other groups. However, the names given are quite sufficient to indicate the type of fauna. There are a number of stropheodontids and spiriferids (not the heavy, costate, near-shore types), yet to be named. The gasteropods are not common and *Hercynella* itself is rare. The other groups, as such, are plentiful. The plants were probably swept out to sea by some river, as *Hedeia* is definitely a land plant. They occur mostly as broken, unidentifiable fragments. In spite of a great deal of collecting, only one determinable fragment has been found. Plants have been collected also in the Bohemian fauna at Lilydale.

Chapman (1917, p. 126) claimed that because the *Hercynella* shells are thin, they suffered from calcium starvation brought about probably by dilution of the sea water with fresh water, and by the deleterious effect of mud from terrigenous sources. Although the *Hercynella* shells at Killara are thin, those of the brachiopods and pelecypods are not; no difference being noted between those at Killara and those elsewhere. Thick-walled *Pleurodictyum* and *Lindstroemia* indicate that there was no lack of calcium salts in the sea water. Moreover, although plants may have drifted out to sea to be associated with the fauna, it cannot be regarded as an area in which the currents of a river were felt. This is shown by the fineness of the sediments, indicating quiet if not deep water; the lack of current bedding, and the presence of a normal off-shore type of fauna. The thinness of the *Hercynella* shells is therefore to be regarded as due to genetic constitution and not to ecological conditions.

The fact that Killara possesses a Bohemian type of fauna makes it very probable that the well-preserved species of *Hercynella* found there are normal marine gasteropods and not pulmonates. Being so thin-shelled, they could probably not stand up to the conditions of the more turbulent near-shore facies affected by tides and currents, and they could certainly not stand up to much transport when empty.

PALAEONTOLOGICAL HISTORY OF PULMONATES

It would appear that certain Tertiary forms which closely resemble extant pulmonates belong without doubt to that class. Unfortunately, zoological definitions cannot be applied to fossil pulmonates, and so analogy has to be one's guide.

But there is no genus which can be readily referred to the Pulmonata earlier than the Mesozoic. *Anisomyon* (a form which the author has not been able to study) is classified as a pulmonate, and dates from the Jurassic. The indubitable pulmonate shells date from Tertiary to Recent. As far as the writer is aware, no gasteropods have been referred to the Pulmonata between *Hercynella* in the Middle Devonian and *Anisomyon* in the Jurassic. This lacuna calls for explanation; the imperfection of the palaeontological record does not appear to be a sufficient answer.

In addition, there is good evidence for believing that aqueous pulmonates have secondarily returned to that environment. Pulmonates in a water habitat have the "lung" filled with water, and apparently oxidation is effected through the membrane lining that organ and through the other surfaces in contact with the water. Such pulmonates may be termed secondary pulmonates. Most of these are freshwater forms, but some are marine, and are found in water up to 10 fathoms deep.

Now if *Hercynella* is a pulmonate, it must be regarded as a secondary pulmonate, because it is found in an undoubted marine environment. But that the ancestors of *Hercynella* left the sea, evolved the pulmonate structure, then returned to the sea by the Middle Silurian is altogether unlikely. Pulmonates on land would depend on land plants for food. No land plants older than Upper Silurian are known, and in most areas they have not been discovered earlier than Lower Devonian.

There is thus strong cumulative evidence from the apparent genetic relationships of *Hercynella,* its palaeoecology, and the general palaeontological history of pulmonates, to support the hypothesis that *Hercynella* is a normal marine gasteropod and not a pulmonate.

Description of Species

A single species of *Hercynella* has been described from Victoria by Chapman (1916), who also commented on the ecology of the genus (1917) Other passing references to the genus have been made (Chapman 1906, 1908, Chapman and Thomas, 1935). Further collecting has brought to light other specimens of this species, and examples of two new species, which are now described.

HERCYNELLA VICTORIAE Chapman

[Plate VII, fig. 4]

Chapman 1916, pp 99-100, Pl. V, figs 47, 48

HOLOTYPE This is the steinkern of an almost complete shell in grey mudstone from Syme's Tunnel, Killara (loc. 34), and is Reg. No. 12858 of the National Museum, Melbourne.

STRATIGRAPHIC POSITION. Yeringian (Lower Devonian).

NEW DESCRIPTION OF HOLOTYPE. Apex erect. Aperture roughly oval. Longitudinal profile as seen in fig. 1a. The keel characteristic of the genus is on the holotype straight, prominent, and with an inward flexure of the shell on each side. The measurements are:

Diameter through keel	5.1 cms. (incomplete)
Diameter at right angles to above ..	3.1 cms. (incomplete)
Height	1.1 cms. approximately

The ornament consists of very fine folds (they must affect the whole thickness of the shell because they occur on both the steinkern and the external mould), about 15 per centimetre. It is faint near the apex but becomes well defined at the margin. Somewhat discontinuous concentric growth lines present.

COMMENT. As Chapman has said, this form is most like *H. radians* of the Bohemian Lower Devonian. It is similar in ornament, and in being a flat type, but differs in the position and nature of the apex, and in the shape of the aperture.

Chapman's paratype (Reg. No. 12857 in the National Museum, Melbourne) is a crushed specimen which shows the nature of the ornament more clearly (14 ribs per cm. were counted).

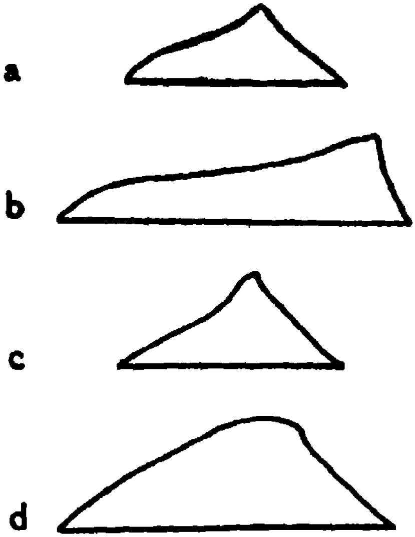

Figure 1.

Median longitudinal profiles of species of *Hercynella* (actual size) orientated so that the end accepted as anterior is on the right of the diagram in each case.

a *H victoriae*, holotype.
b *H. victoriae*, hypotype.
c *H petasoida*, holotype
d *H. killarensis*, holotype.

HYPOTYPE (Pl. VII, fig. 4). A well preserved specimen of this species has been collected from Syme's Quarry, Killara (loc. 35), and is now described as a hypotype. It is a steinkern in brown mudstone, and is Reg. No. 1935 of the collection of the Department of Geology, University of Melbourne. The specimen was collected by Mrs. R. Bowie, of Killara.

STRATIGRAPHICAL POSITION. Yeringian (Lower Devonian).

DESCRIPTION OF HYPOTYPE. Patelliform exoskeleton, with eccentric apex (damaged, but probably erect). Aperture quasi-circular. Keel characteristic of the genus formed by fold extending from apex to margin, and with broad inward flexure on each side. The perimeter of the shell on the fold side is incomplete, but the measurements of the specimen as it stands are:

Diameter through fold	6.0 cm.
Diameter at right angles to above	5.2 cm.
Distance of apex from one end of second diameter ... about	1.0 cm.
Height of apex above plane of perimeter ... about	1.5 cm.

The ornament (as seen on the steinkern) consists of fine radial folds which are hardly discernible in the region of the apex, and which gradually widen towards the perimeter of the shell. Some bifurcate towards the margin. There are about nine folds per centimetre at the margin on the side opposite the fold or keel. The folds are finer where the perimeter comes nearer the apex. The depressions between the folds are about half the width of the latter. There are a few incomplete fine concentric ridges which apparently represent slight variations in growth rate. The longitudinal profile of the shell is shown in fig. 1b. The small distance between steinkern and mould (seen when clearing the fossil) indicates that the shell was thin, nearer the edges at any rate. No muscle scars discernible.

COMMENT. This specimen shows the nature of the margin of the shell on the side on which it is incomplete in the holotype, viz., it is broadly rounded. The ornament consists of folds which affect the whole thickness of the shell; this corrugation would give added strength to the thin exoskeleton.

It will be noticed that the hypotype has a larger ornament at the margin, and that the apex is in a relatively different position from that in the holotype. Both these things are probably mainly due to the larger size of the shell. If the ornament on the hypotype is measured at the same distance from the apex as is the margin on the holotype, it is found to be about the same. Further, as the anterior side of the shell is steep and the posterior shelving, it is clear that with growth the relative position of the apex will be nearer the anterior margin (see p. 81) for orientation accepted for these shells). This does not explain all the difference, but when a larger series of specimens is available, it will be quite easy to settle these points.

HERCYNELLA PETASOIDA, *sp. nov.*

[Pl. VII, figs 1, 2]

TYPE MATERIAL. Syntypes consisting of the external mould (University of Melbourne, Dept. of Geology, Reg. No. 1934) and internal cast or steinkern (Reg. No. 1933) of a specimen complete but for part of the margin; preserved in bluish grey indurated mudstone from Syme's Tunnel, Killara (see Gill, 1945, p. 179, for locality).

STRATIGRAPHICAL POSITION. Yeringian (Lower Devonian).

Description. Depressed conoid; anterior-posterior profile as fig. 1c. Apex rather accentuated through slight crushing (to be expected owing to thinness of shell), erect, nearer one margin than other, i.e., eccentric. Aperture sub-oval. Conicoid shape interrupted by both a keel (elevated) and a sinus (depressed). The angle between these is approximately 70°. Both keel and sinus extend from the apex to the perimeter.

The "ornament" consists of a number of fairly complete concentric ridges; these appear to be accentuated growth lines. There are also some very faint radial lines, which are very much finer (about 5 per mm.) than the prominent radial ornament of *H. victoriae*.

Measurements. The radius on the side opposite to the keel is 2.5 cm. The shell is about 1 cm. high.

Comment. When collecting the fossil, I thought the sinus was an artefact due to crushing, but apparently it is a genuine feature. Like *H. victoriae*, this form has an erect apex, and in this differs from *H. killarensis*, sp. nov. The trivial name is derived from the Greek and Latin word *petasus*, a broad-brimmed hat.

HERCYNELLA KILLARENSIS, sp. nov.

[Pl. VII, fig. 3]

Type Material. Holotype, consisting of a steinkern in grey indurated mudstone, from Syme's Tunnel, Killara (Gill's loc. 34). Specimen complete except for slightly broken margin. Collected by Mr. F. Chapman and housed in National Museum, Melbourne (Reg. No. 14524).

Stratigraphical Position. Yeringian (Lower Devonian).

Description. Patelloid; anterior-posterior profile as in fig. 1d. Aperture sub-oval. Apex eccentric, blunt, and inclined anteriorly. Radial keel or fold extends from the apex to the margin, and is straight; it is rounded and there is an inward flexure of the shell on each side, that on the anterior side being more pronounced. There is a clearly defined but shallow sinus on the anterior side of the keel; the angle between the two is about 70°. A conspicuous outward flare of the margin where the keel meets it is present as in *H. bohemica*.

The ornament consists of a series of concentric undulations. There are traces of a very fine radial ornament.

Measurements.

Diameter through keel	5.5 cms.
Diameter at right angles to this	4.5 cms.
Height .. .. about	1.6 cms.

Comment. This species is very interesting in that the apex is not erect, but incipient enrolment is present as in the allied genus *Calloconus*. The occurrence of a sinus as well as a keel, as in *H. petasoida*, sp. nov., indicates a relationship with this species from the same locality. *H. killarensis* differs from *H. petasoida* chiefly in having a non-erect apex and a different type of keel. In shape the new species resembles *H. nobilis* Barrande, which has two keels instead of a keel and a sinus as in this species under discussion; there is also a similarity of ornament. The apex in *H. nobilis* is very blunt as in *H. killarensis*, but is apparently erect.

In the palaeontological collection of the Geology Dept. of the University of Melbourne (Reg. No. 755), there is an external mould of *H. killarensis* which shows the concentric undulations clearly, and superimposed on these there are concentric lirae. There are traces of these on the holotype steinkern, and are probably better developed on this specimen because it shows the outside surface of the shell.

It is to be noted that in *H. nobilis* there are slight variations in the degree of development of concentric undulations and lirae, and of radial lirae.

HERCYNELLA sp.

In the National Museum, Melbourne, there is a crushed specimen of *Hercynella* from Ruddock's Quarry, near Lilydale (Gill's loc. 20). There is a more or less complete steinkern (Reg. No. 14525) and a piece of the external mould (Reg. No. 14526). It measures about 5½ cm. through the fold, and about 3.7 cms. along a diameter at right angles to that. The fossil has the conspicuous radial ornament of *H. victoriae*, but at the distance from the apex where that species has 15 ribs per cm., this specimen has 21. Its chief interest is that it occurs in a different district, and constitutes another facies and stratigraphical link between the Lilydale synclinorium and the Killara synclinorium.

Stratigraphy

The species of *Hercynella* described in this paper have come from the two main outcrops of Lower Devonian beds of Bohemian facies in Victoria—Lilydale and Killara. None has been found in the areas of outcrop of Lower Devonian beds of Rhenish facies, such as at Kinglake. Once again, too, the forms most like those from Lilydale and Killara are to be found in the Lower Devonian beds of Bohemia.

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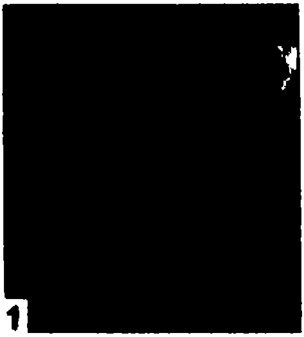
Description of Plate

PLATE VII

All figures approximately same size

Fig 1—*Hercynella petasoides* sp nov external mould Syntype.
Fig 2—*H petasoides* sp nov steinkern (internal cast, as defined by Knight, 1941) Syntype
Fig 3—*Hercynella bellerensis* sp nov steinkern Holotype.
Fig 4—*Hercynella victoriae* Chapman steinkern Hypotype.

The photographs were taken by Mr L A Baillot, of the Melbourne Technical College to whom the author s thanks are due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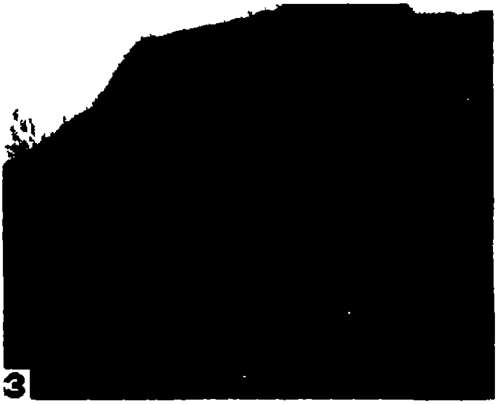
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Species of Hercynella

8—The Origin of the Tetrapods

By H. LEIGHTON KESTEVEN, D.Sc., M.D.

[Read 12th December, 1946]

Introduction

In 1915 W. K. Gregory expressed the opinion that the Dipnoi and Crossopterygians were derived from a common ancestor. Since then palaeontologists have shown an increasing tendency to regard the latter as the direct ancestors of the tetrapods. This belief is given very definite expression by Jarvik (1942) who derives the Urodela from one crossopterygian group, and the Anura from another.

In their recent contributions to the problem of the origin of the tetrapods palaeontologists have devoted a great deal of attention to attempts to "restore" the soft anatomy of the fossils. In view of the fact that these highly speculative studies are receiving more than a passing recognition, a critical examination of the work seems to be called for.

The present contribution is divided into three sections. The first is an attempt to assess the value of the methods of the palaeontologists by applying them to recent forms. The second section is devoted to brief reviews of some of the contributions. The third presents evidence which, it is believed, indicates that the dawn of the tetrapods probably antedated the appearance of the Crossopterygia.

Section I

THE FACTUAL EVIDENCE

This is, of course, provided by the fossils themselves. The skulls provide (1) dermal shield patterns, (2) neurocrania or neurocranial casts, (3) the bones of the palatoquadrate and (4) branchial skeleton. In addition, elements of the skeleton other than those of the head may be available for study, but these enter so little into phylogenetic studies that they may be neglected here.

(1) The Dermal Shield, when complete, is usually characteristic of the class to which the fossil belongs and by comparison with these, the less complete specimens can, in the majority of instances, be identified with a good deal of confidence.

The value of the dermal shield patterns for phylogenetic studies may be tested by attempting to determine the natural classification of the recent forms on such evidence, and such a test throws the gravest doubt on their value. I have illustrated (Fig. 1) the dermal shields of several acanthopterygians. It is suggested that if these had been fossils it would not have been possible to recognise that they were closely related forms on this evidence. A very marked illustration of this unreliability of the dermal shield patterns is provided by those of *Accipenser* and *Polyodon* or *Psephurus*. There is no doubt that if we were to attempt the natural classification of the lower tetrapods and fishes on the evidence of their dermal shields we should fail completely. *There is no reason for believing that the Dermal Shields of the fossils are any more reliable.*

(2) The Neurocrania and their attached sense capsules, like the dermal bones, are characteristic of the class to which the fossil belongs. Especially is this so if the boundaries of the component and covering bones can be determined. In the absence of these boundaries, or, in other words, if known from casts showing contours only, the specimen may not be readily identifiable. It is difficult to

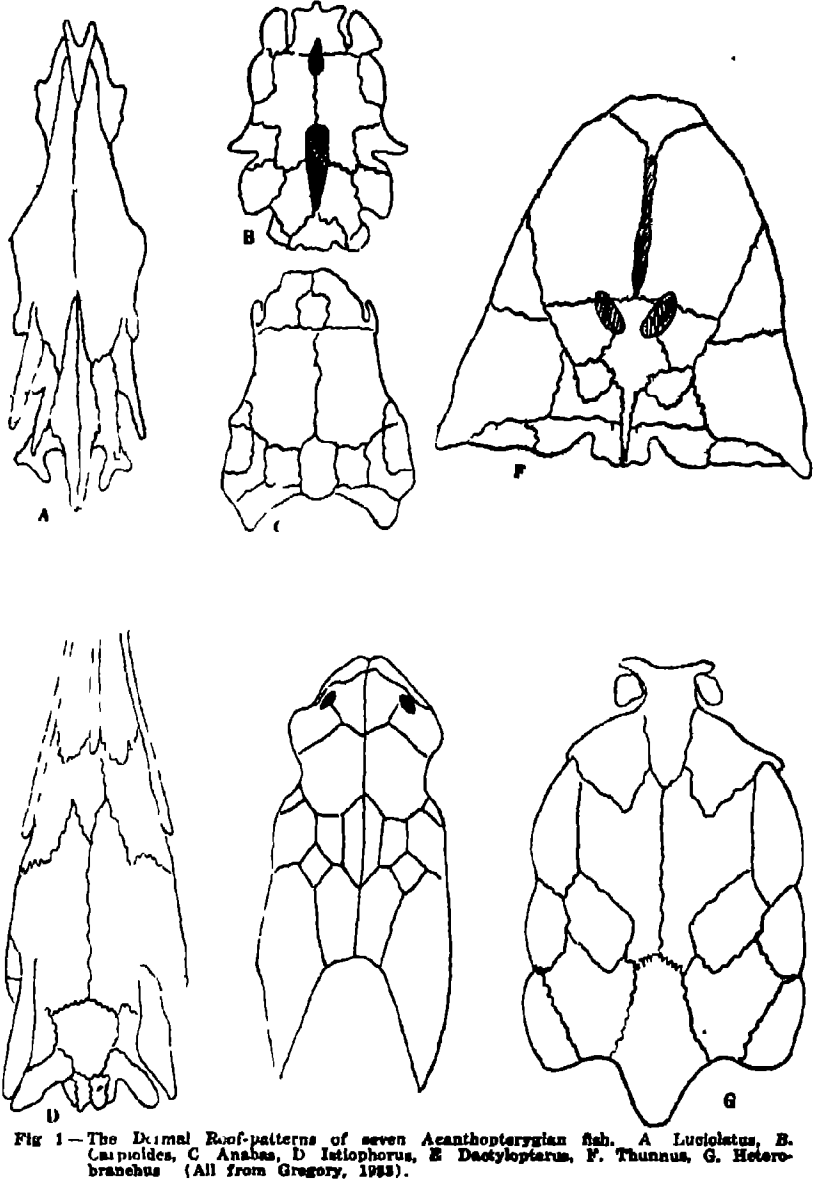

Fig 1.—The Dermal Roof-patterns of seven Acanthopterygian fish. A Luciolatus, B. Caspioides, C Anabas, D Istiophorus, E Dactylopterus, F. Thunnus, G. Heterobranchus (All from Gregory, 1933).

make comparison between the fossil material and the recent, because when the skull of a recent form is taken in hand, all the details of its architecture may be studied. It is probable, if the neurocranium of such a fish as *Tandanus* were found devoid of all suture lines between the bones, it would not be identified as that of the fish. The skull in question is platybasic, devoid of a myodome, and it is one of the very few fish in which the outer wall of the trigemino-facialis chamber is missing.

(3) The Bones of the Palato-quadrate are remarkably constant in number throughout the whole of the vertebrata, but they are very variable in degree of development and arrangement. Notwithstanding this variability, each arrangement is, in the majority of instances, characteristic of a particular class. In the fossil, as in the recent forms, these bones usually permit a ready recognition of the specimen, but, as with the dermal shield pattern, it would be quite impossible to arrive at a natural classification of the recent tetrapods and/or fishes on the evidence of the bones of the maxillo-palate alone.

When they are present along with the whole of the bones of the neurocranium, then, in the fossil specimens as with the recent, they may be used for phylogenetic studies, and with the same limitations. The limitations in question are those due to a lack of knowledge of the soft anatomy and embryology of the specimen These limitations have been recognised by the palaeontologists, and they have attempted to "restore" or "reconstruct" the soft parts.

THE RESTORATIONS

These have been devoted to attempts to visualise the brain, the constitution and distribution of the cranial nerves, the location of main blood vessels and the cephalic musculature.

(1) The Restoration of the Brains of the fossils has been carried out under the direction of two factors. The first of these is the shape of the cranial cavity, the second is the restorer's own belief as to what the brain should be like. The brains have been roughly fitted to the cavities, but their contours within the cavities have been determined by the affinities which the fossil was believed to exhibit. Thus, if the fossil, known to be a fish, was believed to show amphibian affinities, the detailed form of the brain was made to show similar affinities The influence of this second factor was quite unavoidable. The mould of the cavity itself does not give any details of brain form, and these must, therefore, be filled in by the restorer It is obvious that they cannot have been filled in haphazardly, the work had to be carried out according to plan, and this will, very certainly, have been dictated by the convictions of the restorer In effect, the restoration is a pictorial presentation of the following statement:— The general form of the fossil indicates that it was probably allied to the class M. or N., and, therefore, its brain will have had the general form of that of the members of the group All the detailed work which has gone into the restoration does not give it any greater value than this bald statement would have had.

Watson (1925, p. 848) wrote "the cerebral hemispheres, *if* we may judge from the character of the chamber in which they lay" were of a certain shape. The value of all these restorations of fossil brains rests upon the correctness or otherwise of the assumption made in this sentence, and this is an assumption which may be tested by comparing the brains of recent lower tetrapods and fishes with the chambers in which they lay.

The mould of the cavities present in the neurocranium of *Paradicichthys venenatus*, Whiteley, is depicted below (*Fig.* 2A). This

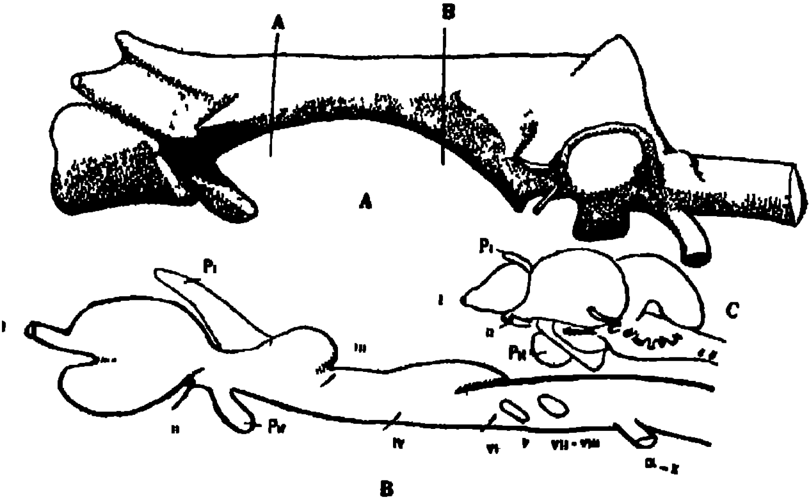

Fig 2—A The cast of the cranial and ethmoidal cavities of *Paradicichthys venenatus*, Whitley.
B A "restoration" of a brain to fit these cavities.
C The outline of a typical teleostean brain drawn to about the same scale. Pi. Pineal body Pit. Pituitary body

is a typical acanthopterygian, and the brain had the form shown (Fig. 2C). The mould recalled so strikingly that of *Megalichthys* that it was deemed worth while "restoring" a brain to fit it (Fig. 2B).

The next drawings present two views of the cast of the cavities in the neurocranium of *Amia*, and a "restoration" of the brain (Fig. 3).

In this case, as in that of *Paradicichthys*, all cartilage and connective tissue was removed before the mould was made, in order to reproduce conditions as they would be in a fossil.

The making of these moulds and their illustration may appear to some as a work of supererogation, because they illustrate a fact already well known to practical comparative anatomists, *viz*, that the cranial cavity does not reflect the shape of the contained brain except in the theria. Not only is the mould of the cavities not like the contained brain, but it is very commonly very unlike it. This is due, of course, to the fact that the brains of the lower tetrapods do not nearly fill the cranial cavity, but are suspended, commonly well away from the walls, by loose, open-spongy connective tissue. In the case of the fossils, the moulds of the cranial cavities are likely to be even more misleading, because the cavity in many forms is limited by cartilage and/or connective tissue. If this had been so in the fossil, the cavity as found would be quite unlike that in which the brain was housed.

It is to be concluded that these restorations of the fossil brains may be quite unlike the original brain and should not be regarded as other than pictorial expressions of opinion

(2) The value of the restoration of the Constitution and Distribution of the Cranial Nerves and of the blood vessels of the fossils cannot be tested by attempting similar exercises with recent forms as the subject The reason for this is that there could be no doubt about the identity of the specimen upon which the test is to be made Provided the work was undertaken by a competent anatomist it would be approximately correct in every instance This very fact however throws grave doubts upon the value of such restorations in the case of the fossils The work on the recent forms would be correct because the restoration would follow the well known arrangement of the nerves and blood vessels in related forms In fact it would be dictated entirely by a knowledge of the anatomy of the other forms In precisely the same way the restoration of these things in the fossils has always been dictated by a knowledge of the anatomy in forms to which it is *believed* they were related It would be quite impossible to attempt the restoration of the anatomy of a fossil except under such direction

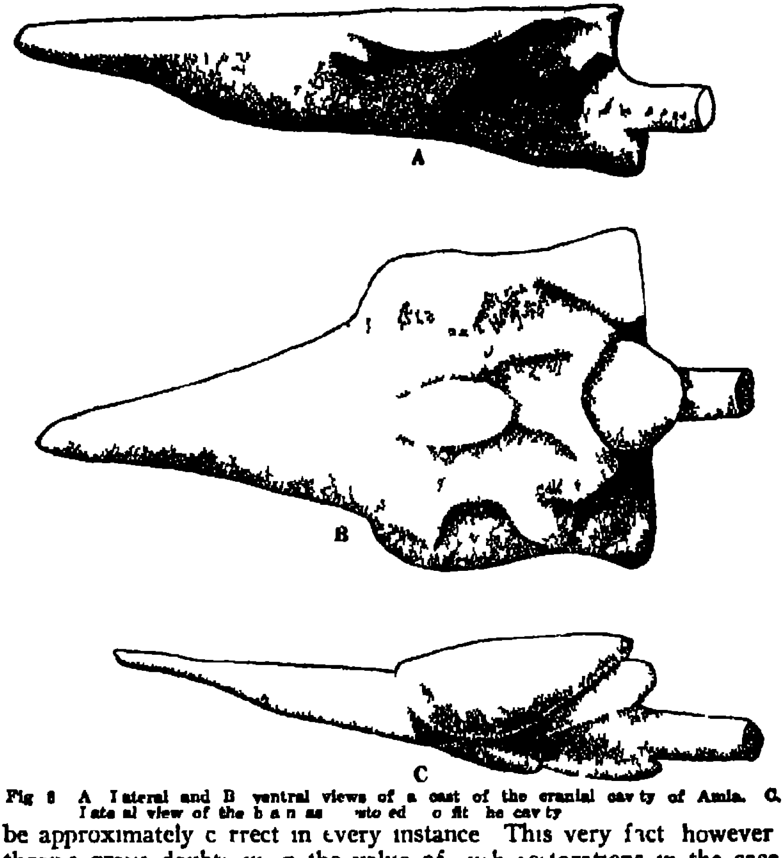

Fig 8 A Lateral and B ventral views of a cast of the cranial cavity of Amia. C. Lateral view of the brain as restored to fit the cavity

It follows that they are nothing more than detailed presentations of convictions as to the relation of the fossils to other forms — "Since this fossil appears to be related to M. or N., the distribution of its nerves and blood vessels was probably similar to that of those forms."

(3) The Restoration of the Cephalic Musculature may be undertaken with a good deal of confidence if the attempt is confined to the muscles of mastication. The skeleton will present the mechanical factors in the problem, and over and above this the actual points of origin and/or insertion are at times impressed upon the bones. Here again, however, one must be guided in the work by the number and general disposition of the muscles in related forms. If, for instance, the attempt were made to restore the muscles of a crocodile, under the impression that the specimen was an amphibian, the result would be quite astray from reality. On the other hand, assuming that it was a reptile, the result would, in the hands of a competent anatomist, approximate closely to actual conditions.

Once more the work must be directed by a knowledge or assumption of the class to which the fossil belongs. "Because this is a member of the group M. or N. the arrangement of its musculature was probably similar to that of the members of the group"

It is quite clear that these restorations are all very largely dictated by beliefs or convictions already held before they were undertaken. They are the result of convictions, and, therefore, should not be quoted as evidence in support thereof; they are not evidence at all, they are opinions. Too often in our endeavours to understand the way of evolution we are compelled, for want of definite evidence, to say, in effect or actually, "if this be true we may further assume." Although regrettable, this procedure is permissible so long as the "if" is properly recognised. When the argument continues —in *fact* this cannot have been otherwise — it is neither permissible nor excusable. The second statement cannot be accepted as fact if based upon an assumption, and it should not be presented as such. I quote three examples of this reprehensible practice.

Watson (1925, p. 848): "the cerebral hemispheres, *if* we may judge from the character of the chamber in which they lay, were long and of considerable size. *In fact,* the brain as a whole cannot have differed greatly from that of Ceratodus or an amphibian."

Romer (1937, p. 34): "It is obvious that the brain as restored is essentially similar to that seen in dipnoans on the one hand and amphibians on the other; thus, the neurological evidence, as far as it goes, agrees with all other lines of work tending to indicate the close relationship of crossopterygians with the two groups. Of particular interest is the *fact* that the forebrain is here highly invaginated as in the amphibians — —."

Jarvik (1942, p. 489) states that there are very considerable differences between the snouts of the Osteolepiformes and the Porolepiformes, and then proceeds to detail these in twenty-six numbered paragraphs. All are given as statements of fact. Of the twenty-six features, seventeen are based upon an assumption, they are restorations.

Section II

My criticism of some of the Palaeontological contributions is couched in emphatic language; to some it may appear unduly blunt. No apology is offered for the language used, but some explanation of it is certainly called for.

In effect, it has been stated again and again that our palaeontological colleagues have deliberately distorted facts to make them fit their theories on the origin of the Tetrapoda. "Deliberate distortion" is usually a dishonest procedure; in this case it is most emphatically not so regarded, and it is sincerely hoped that such an implication will not be read into the arguments presented.

The convictions of our palaeontological colleagues are very real to them, and under the drive of these convictions they have quite honestly contended for their theories. The colour-blind man sees the scarlet robe and the green lawn the same colour, to him they *are* the same colour, but he is wrong. The Physicists have proven him so Just so, it is argued in these pages, the palaeontologists, blinded by the early workers, are wrong.

Before proceeding to discussion of some of the individual contributions, some further general criticism of the whole of them may be offered.

Palaeontologists have, each of them, a faith in the correctness and reliability of their restorations and interpretations of the fossils which is not justified by experience. In support of this it may be pointed out that specimens have been studied by thoroughly competent palaeontologists, and later the same specimens have been studied by other, equally well-qualified, palaeontologists and each later student has decided that his predecessor was at fault in his interpretation and/or reconstruction. Perhaps one of the most striking examples of this sort of thing is provided by the following extract from D. M. S. Watson's Croonian Lecture (p. 234). "The neutral cranium of the osteolepids was first, though quite inadequately described by Rohon, later, and again misleadingly, by myself and H. Day and by E. A. Anderson, and finally and more successfully by W. L. Bryant. Dr. Bryant's description is, as Dr. Stensio informs me, and as I have been able to confirm, from an examination of the original material, inaccurate in certain respects." That was in 1926, and Watson used the then accepted interpretation in his work on the evolution of the Amphibia. On top of all this examination and re-examination, in 1936, one of the specimens studied by Watson and Day was examined by Säve-Soderbergh and he writes (1936, p. 137), "By means of our modern technical outfit I was able to clean out perfectly the dorsal and lateral, and part of the ventral, surfaces of the neutral endocranium of this specimen, and to demonstrate a number of interesting points, which partly also change the interpretation of *Osteolepis* and *Eusthenopteron*."

The next general criticism which one feels impelled to make is to the effect that their work at times exhibits an unjustifiable degree of originality. The reference here is to the interpretation of foramina and grooves which they find on the fossils. Those who have had experience in actual dissection know that the identification of any but the main nerve and vascular foramina cannot be attempted, and that, except at and close to the points of egress from the cranium, these structures are only exceptionally in contact with bone at all. Whilst sorry to speak so strongly as to offend or to risk giving offence, one cannot refrain from stating that these claims — to be able to determine the course and even the constitution of nerves and the number of cranial roots they had — must appear to be little short of ridiculous to all who have spent years in the laborious study of those things with scalpel and microtome.

As a matter of sober fact, the most that could be said on being presented with a skull, recent or fossil, complete or fragmentary, not being one which had been studied in the flesh, or which has been worked out by another investigator, is that — this is a fish, or perhaps an amphibian skull and therefore its nerve distribution and vascular arrangement were probably similar to the condition found in some related form. Although this is so, statements like the following are not uncommon. "The seventh nerve arises by a single root, so far as can be seen from the skull" (Watson, 1925, p. 845). To the student of the anatomy of living animals, statements like this are just fatuous. It is well known that the number of roots a nerve may have is never indicated on the skull, nor could it be.

Most palaeontologists, in their evolutionary equations, give too high a value to the factor provided by the arrangement of the dermal roof bones. It is fully realised that this criticism is founded to a large extent on the personal attitude; in other words, this is a matter of opinion and not, like the last, a statement founded on facts. One of the most outstanding of the latest contributions which base a classification of the vertebrata largely upon a possible chain of changes in the dermal roof bones is that of Säve-Söderbergh (1934-1936). Doubt as to the value of his evidence is centred in the fact that so many different roof patterns are presented by closely-related animals.

The Dipnoi alone present a whole series of such patterns. In order to base any scheme of evolution on the roof patterns, one has to *select* the examples of fishes and tetrapods, and to neglect the patterns of a number greater than that used in the comparisons. The marked variability in the dermal roof pattern has always appeared as evidence that those bones were, and in the living Teleostei still are, unstable and subject to non-significant variation. In short, it appears true to say that, amongst the fishes, there is no uniform plan of dermal roof pattern. It is as easy to select examples which would provide a chain of changes leading to the tetrapod pattern from the living teleosts as from the Crossopterygians. A selection of patterns drawn from modern fishes has been illustrated (fig. 1), and it was suggested that if these had been fossils, it would not have been possible to decide that they were really closely related forms, on this evidence.

It is submitted that the evidence points to the conclusion that the dermal roofing bones of the fishes are still in a condition of flux. If that be so, then it is further submitted that this is evidence which should lead us to expect that the roofing pattern was in at least as unstable a stage of evolution in devonian times as it is to-day.

It will probably have been noted that Säve-Söderbergh was unable to make use of Goodrich's careful analysis (1930) of the evidence and determination of a fundamental pattern in his last essay.

Säve-Söderbergh's concept of the composition of the dermal roof of the common ancestor of the Crossopterygians and Stegocephalians is apparently in the nature of an addition sum. It appears that he has listed all the bones found in the many fossils and endowed the hypothetical ancestor with the lot. He then proceeds to argue from this hypothesis as though it were a statement of fact. Unfortunately, no fossil is known which possessed the full list.

Far from his hypothesis being a statement of fact, it is arguable, on the evidence of the paucity of the number of bones in the *most* primitive fish forms known (the Arthrodira and the Antiarchi) and the wide diversity of the patterns in the *less* primitive, that these *latter* patterns have risen independently, and that there was no general plan from which they were evolved. If, however, we grant that Säve-Söderbergh's hypothesis is sound, we may also accept his following statement, which was that each of the many elements may alternatively have — (1) remained unchanged, (2) become fused with other elements, (3) become secondarily subdivided, or (4) reduced even to extinction. It is just the possibility of all these alternatives which detracts from the value of speculation on the assumption that any one or more of them has brought about the particular pattern derived. That there have been instances of persistence and of all three modes of change there is little reason to doubt, but there is nothing to guide us in determining whether reduction in number was due to deletion or fusion. True, when we find reduction in the number of a transverse row, we are justified, on the parallel of embryological evidence, in concluding that the bone which, in the more numerous row lodged the lateral line organ, has persisted. Whether the other has been lost by deletion or fusion will still remain for choice by the personal belief alone. It is the constant and unavoidable intrusion of this personal factor which makes all these theories unconvincing.

Säve-Soderbergh and Stensio are agreed that reductions in number have, in the great majority of the instances, been due to fusions. In support of this belief, the former asserts that modern embryological investigations ("Pehrson, 1922, and others") have confirmed the views of Stensiö "in this respect." Watson, on the other hand (1921), states his belief that the reductions were due to deletions.

Pehrson demonstrated that the dermal roofing bones of *Amia* were developed by the fusion of more than one centre. This is probably the evidence referred to by Säve-Soderbergh. An analysis of Pehrson's work reveals the fact that the roofing bones of *Amia* are developed by the fusion of at least forty-two centres. Now, if these are of phylogenetic significance, in the way suggested by the reference, the forty-two centres should represent separate bones in some ancestor. By this interpretation the rostral represents four bones, the nasals each three, the frontals each four, whilst the circumorbital bones represent an indeterminate number. It is exceedingly doubtful whether anyone will accept such an interpretation, yet it is the only logical inference from such a reference.

Now turning to Watson's attitude. The vast majority of embryological investigations bearing on the subject at all reveal that in vertebrates, membrane bones are, in all but exceptional instances, developed from one continuous aggregation of osteogenetic tissues, and further than this, that in a great number of instances where the future bones are to make sutural contact, their stromata are originally continuous (Vide Kesteven, 1942, p. 224).

Although the great weight of embryological evidence lies in favour of the attitude of Watson, it does not dispose of the possibility that fusions have taken place. The exceptional instances of fusions are probably *definite* evidence that they have, but there is another interpretation. It is as follows: *A priori* all will agree it is probable that dermal covering bones have been evolved by the coalescence of dermal ossicles and the submergence of their fused bony bases; in which case, it must be agreed that all these bones have resulted from the fusion of very many small centres of ossification, and it may be that the sutures between the individual bones indicate original fracture lines imposed by mechanical strains and stresses, as suggested by Gregory (1915) If this be so, then the number of centres of ossification of lateral-line organ bearing bones in the fishes is without any significance relative to the number of bones incorporated into each of them.

Säve-Soderbergh concludes his polemics (1935, p. 202): "Thus, the study of the Stegocephalians from Greenland has caused not only a thorough revision of the morphology and classification of the Labyrinthodonts, but also a revision of larger groups, resulting in a totally changed classification of the Gnathostome Vertebrates."

Unfortunately, all our attempts at unravelling the tangled problem of the evolution of the Vertebrata are unavoidably compounded from facts *and* our personal interpretation of them. The personal factor cannot be excluded, the evidence is incomplete, and the problem may not be stated as a mathematical formula. None of us, therefore, is entitled to use expressions which convey the impression that the theory advanced is a proven one

THE INTERPRETATION OF THE CROSSOPTERYGIAN NEUROCRANIUM

Save-Soderbergh (1936) and Romer (1937) have both attempted to interpret the neurocranium in detail Exception must be taken to both these efforts because neither writer compared his fossil with the fishes Without any doubt whatever, both these neurocrania were those of fish, nor do they depart from the general shape and proportions of those of recent fishes. The only marked difference is the break between the anterior and posterior parts The truth of this statement is brought out by the comparison of the four neurocrania illustrated (Fig 4) The most striking features on the side wall of the occipito-otic mass in all four are the outer wall of the trigemino-facialis chamber, and the two foramina related to it. These are the most constant and characteristic features in the fish cranium, and the association of the hyomandibular branch of the facial nerve with the hinder of the two foramina and the maxillary and mandibular branches of the fifth nerve with the anterior are just as constant as the bony features. If these features and this constancy of nerve relation are not the result of direct inheritance from the common ancestral group of fishes, how comes it that not only all the modern fishes but all the surviving ganoids exhibit them? If it is an inherited feature then surely it is present in both *Rhisodopsis* and *Megalichthys* It is submitted that the features *are* present in both these neurocrania and that they should have been recognised.

In all the recent fishes the basisphenoidal region of the skull terminates just in front of the trigenino-facialis chamber, and the pituitary body lies at, or very close to, the anterior boundary of the chamber.

Both Säve-Söderbergh and Romer identify an outstanding process of the ethmo-sphenoidal mass as a basipterygoid process. The basipterygoid is a process of the basisphenoid bone. This is a basicranial element which, throughout the whole of the vertebrates sutures with the basioccipital bone. These writers follow Watson (1925) in their identification of the basipterygoid process, but, even so, it is doubtful whether the consequential interpretations were recognised by them. If the basipterygoid process was located on the ethmosphenoidal mass then the basioccipital was hinged, not sutured, to the posterior edge of the basisphenoid, and it extended as far in front of the trigemino-facialis chamber as it did behind it. This is a condition which is absolutely without parallel anywhere else in the vertebrate series. There is neither animal nor fish known, in which the basioccipital extends forward beyond the foramina of exit of all the branches of the fifth and seventh nerves.

As a matter of fact, the ethmosphenoidal masses of these two neurocrania are capable of interpretation as perfectly normal fish specimens, absolutely comparable with those of recent forms The "basipterygoid process" compares very closely with the postero-lateral corner of the ethmoid in recent fishes, and the cavitation in that of *Megalichthys* is very similar to that in the neurocranium of *Paradicichthys* (vide Fig. 2).

The attempt will not be made here, but it is believed that if these two neurocrania were carefully compared with those of the surviving ganoids and modern fishes it would be found possible to interpret all their main features in harmony with those of fishes generally

Romer, at least, was aware of some of the implications of his interpretation. At the bottom of page 46 and top of page 47 he details the changed proportions in antero-posterior distribution of the various regions and foramina in his specimen.

Romer says of *Megalichthys* that it "may be taken as typical member" of the rhipidistian crossopterygians (p. 44), and there is no reason to doubt the correctness of this statement.

It now becomes necessary again to stress the essential and fundamental similarity of the fossil crossopterygian neurocrania to those of the recent crossopterygians, *Latimeria* and *Polypterus*, and also to those of *Amia* and the modern fishes generally.

It follows that if we accept the interpretation given by the palaeontologists of the crossopterygian neurocrania as correct, then we must try to visualise a re-arrangement of the brain and nerves in all these others to bring about that disposition of these structures which we know to be common to every one of them; crossopterygian and moderns alike, and all this without any change in the general shape and/or proportions of the neurocrania. We have further to suppose that the basisphenoid bone has migrated back along the base of the skull till it reached the position it occupies in all these others, and without any change in other bones or cranial proportions.

For the writer, at least, this is too difficult an exercise in imagination.

There is another possible explanation, *viz.*, that the whole of the recent fishes were derived from the Actinistia, which would be deemed to have differed fundamentally from the Rhipidistia. There is no evidence in support of such an explanation; it would be merely an assumption, necessitated by acceptance of the interpretation of the rhipidistian neurocrania.

"On the Coelacanth Fish" D. M. S. Watson (1921).

Doubtless Watson's descriptions and illustrations of the fossils present the characters and contours of their component parts correctly. This being granted, his identifications of some of the bones, and the interpretations he gives to their features, are incomprehensible to the student of the crania of modern fishes.

That which he identifies as the basisphenoid is a bone which satisfies all the criteria of a presphenoid ossification; such, for instance, as that of *Amia* (Fig. 4c).

The bone which it has been agreed upon to designate basisphenoid throughout the fishes, other than in this coelacanth *Macropoma*, is placed entirely in the floor of the neurocranium in front of the pituitary fossa. If in an attempt to identify this "basisphenoid" bone in *Macropoma*, one disregards the fishes and turns to the lower tetrapods, one would still be at a loss to find a basisphenoid bone which, like this, belied its name as a basal bone and extended to the roof of the cranium.

The absence of ossification in the "lower part of the basisphenoid" (p 322) increases the similarity of this bone to the sphenoid ossification of *Polypterus*

A comparison of Watson's figures 1 and 2 leads to the belief that he has failed to recognise a fracture of the base of the cranium immediately behind this sphenoid ossification. Behind the fracture, it is now suggested, the posterior portion of the parasphenoid with a normal ascending flange has been displaced upwards, and this bone, which Watson identifies as the prootic, is really the posterior moiety of an expanded parasphenoid, which, as in *Polypterus*, covered an entirely cartilaginous portion of the otocrane.

That the inner surface of an extensive "prootic" should be a plane surface devoid of otic recesses is hard to believe. The prootic is a bone developed endochondrally in the anterior portion of the capsule. On the other hand a plane internal surface would be natural to, and quite in conformity with, the mode of development of an ascending expanded posterior portion of the parasphenoid bone.

Stensiö was perhaps correct in his belief that this "prootic" included an opisthotic element. It is probable that better material will disclose a suture interrupting the continuity with the posterior of the two superior wings of the bone.

The skull of *Macropoma* as interpreted by Watson is completely anomalous but if we visualise the so called prootic moved down and just a little backward leaving a gap filled by cartilage in the fresh skull between it and the sphenoid ossification and then fill in a suture across the lower end of the posterior superior wing the skull becomes essentially similar to that of *Polypterus*

Watson s identifications of the components of the palate are subject to the grave suspicion that he has been unduly biassed by a desire

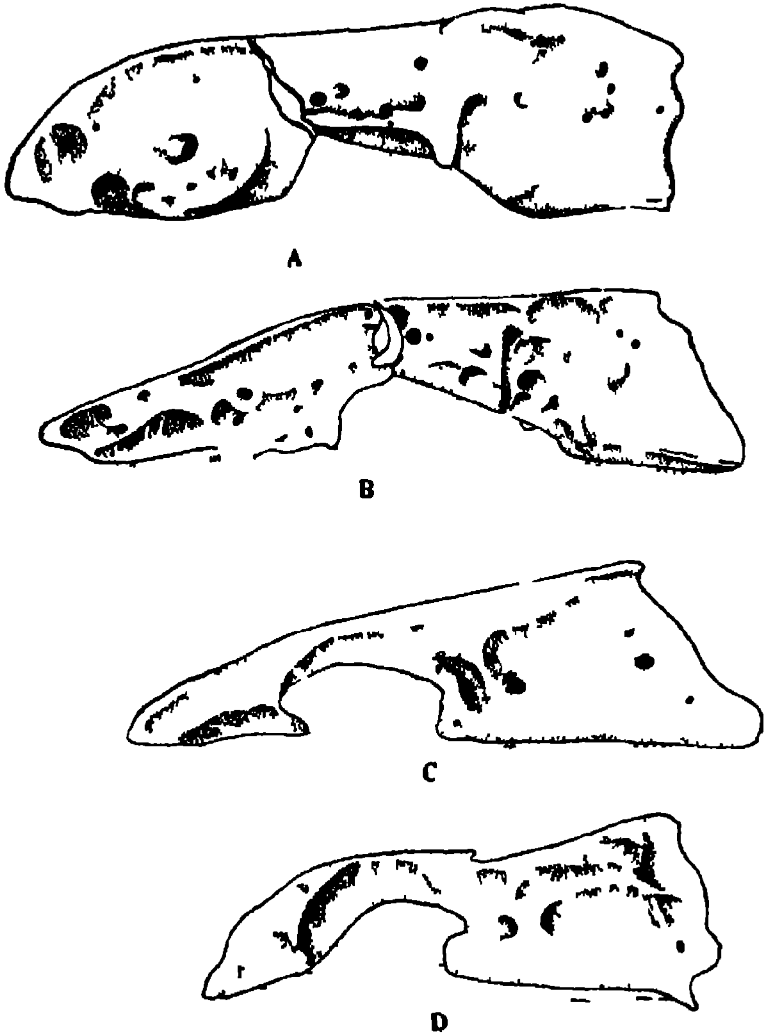

Fig 4.—Crania of A. Rhizodopsis (from Säve-Söderbergh , B Megalichthys (from Romer) C Amia (from Allis) and D Epinephelus. The actual or probable situation of the parasphenoid bone, and interbital septum has been indicated in dotted lines.

to find resemblance rather to the lower tetrapods than to the fishes. No attempt was made to interpret the observed features by comparison with known fish crania.

He tells us that the bone which has been previously identified as a "hyomandibular" by most authors "has been" correctly determined by Stensiö as a "metapterygoid." In the explanation of his figure 5 he introduces confusion by equating the metapterygoid with the epipterygoid. It is hardly necessary to point out that the metapterygoid bone of the fishes is not part of the quadrate and, therefore, cannot, by any stretch of the imagination, be regarded as homologous with the epipterygoid bone of the reptiles.

If Watson's description of the coelacanth palate and palatoquadrate be correct, it follows that the whole structure was attached to the skull only by "tough membrane" between the mesial margin of the pterygoid and the parasphenoid. This is hard to believe.

When it is remembered that hyoid suspension of the quadrate characterises every known fish, it is exceedingly difficult to accept the interpretation offered. The assumption that the hyomandibular is absent presents itself as entirely gratuitous, and depends on nothing but a failure to find. A much more reasonable explanation of its absence would have been to assume that so much of it was cartilaginous that any bony portions which may have been present had been displaced by the rotting of the cartilaginous portion. Since the work was written (in 1921) Smith's description of the living Coelacanth *Latimeria* has appeared. The hyomandibular of this fish is largely cartilaginous.

The following passage calls for criticism:—"The metapterygoid, certainly an ossification on the palato-quadrate cartilage . . . agrees closely with one of the continuous series of ossifications which occurs in cartilage in Osteolepids and rather strikingly with the epipterygoid (!) of an Embolomerous Labyrinthodont which I am describing shortly. There can be no doubt that the bay in its upper edge transmitted the maxillary and mandibular divisions of the fifth nerve, and that the ophthalmicus profundus passed out in front of it" (p. 333).

If this passage had been worked as below, it would not have been open to the objection that expressions of opinion are given as statements of fact — "The metapterygoid, probably an ossification on the palato-quadrate cartilage . . . agrees, etc., . . . *It is believed* that the bay on its upper edge transmitted the maxillary and mandibular divisions of the fifth nerve and that the ophthalmicus profundus passed out in front of it"

In its original form the whole passage is unacceptable. If Watson had stated that *he* was certain and that there was no doubt in *his* mind, that would have been all his material justified him saying. Even as a statement of opinion the passage would be open to criticism.

In view of the fact that these branches of the fifth nerve very rarely impress their course on bones of the suspensorium or palate in living fishes, either teleost or ganoid, and that they all issue well in front of the articulation of the suspensorium with the skull, the course postulated by Watson is absolutely without foundation on fact or analogy. One is forced to the conclusion that the only reason for giving such an interpretation to the "bay on its upper edge" was the author's desire to increase a fancied resemblance of this fish "metapterygoid" to the "epipterygoid" of the embolomerous amphibians[*].

Watson returns to the presumed absence of the hyomandibular on page 336, where we find the following:—"As Stensiö has pointed out, we have in coelacanths a complete loss of the hyomandibular as a supporting element of the jaw. This loss is an *exact parallel* to that which has occurred in Tetrapods and Dipnoi." (The italics are mine).

This last statement is very far from true. Edgeworth demonstrated quite definitely that the hyomandibula is developed in *Ceratodus.* Even if we regard the vestigeal hyomandibula of *Ceratodus* as being without significance in the present connection, there is still no parallel at all between the conditions found in the Coelacanths and the Tetrapods and Dipnoi.

In the former the quadrate is separated from the skull by a hyomandibula bone and a metapterygoid, which latter is so like the metapterygoid of *Amia* and *Polypterus* that there is little doubt that it is the same bone. This cannot, by any stretch of the imagination, be homologised with the epipterygoid. The epipterygoid of tetrapods is undoubtedly the homologue of the processus ascendens quadrati, and is developed endochondrally, that is to say, it is a true cartilage replacement bone, the metapterygoid of the fish is developed ectochondrally and extended beyond the cartilage as a membrane bone and is not a part or process of the quadrate The long gap between the quadrate and the skull was in all probability filled, in the living coelacanth fish, by a cartilaginous or largely cartilaginous hyomandibula (page 106).

In the tetrapods the hyomandibula has been reduced to the stapes and the quadrate is attached to, or articulates with, the skull. Its final evanescence has been demonstrated by Edgeworth in *Ceratodus.*

Clearly there is no parallel here

A *"The Structure of Certain Palaeoniscids and the relationships of that Group with other Bony Fish," D. M S. Watson* (1925)

B *"On Some Points in the Structure of Palaeoniscid and Allied Fish," D M S Watson* (1928).

The critical reading of these two communications gives rise to two general impressions, firstly, that the writer has brought to the work a familiarity with the cranial osteology of the mesozoic fossil amphibians; and that, in the absence of counterbalancing knowledge of the cranial structure of the Teleostei and Ganoids, the whole of the work has been unduly influenced by the knowledge he had. Secondly, one feels that the writer has served but a short apprenticeship with the scalpel and the dissecting tweezers, for he displays a peculiar courage in his identification of the various foramina and grooves which he finds in his fragmentary fossils. Such courage could hardly be possessed by one familiar with the difficulties of dissection and the unreliability of features in the modern forms of the same character as those he relies upon.

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[*] If these latter had already cast the ascending process loose to constitute an independent epipterygoid, it is hard to understand why no recent amphibians exhibit such a feature.

In the result, his reconstructions of the coelacanths are interpreted to harmonise, not with fishes generally, but with the embolomerous amphibians, and with other poorly-known fossil fish.

In the following brief review it is assumed that his statements of *fact* are truly recorded, and depicted with approximate correctness in the illustrations. On these assumptions an attempt will be made to compare the structures with completely known fish. This attempt is made because it appears desirable to demonstrate that, when viewed in the light of complete familiarity with forms whose osteology is perfectly understood, all the features hitherto recorded of the known fossil fish are capable of being more or less perfectly harmonised with those of the modern forms.

Experience teaches that when, having dissected and determined the soft structures related to the foramina and grooves which a particular skull betrays, one takes in hand another with *similar* osteological features (be it noted not with *approximately* or *nearly* similar), one feels entitled to interpret all its features in terms of the dissection already carried out. Experience also teaches that even with this conservative procedure, we are liable to make mistakes. When, on the other hand, the disposition of the bones and the foramina are different from those of our dissected example, we do not feel entitled to guess at the interpretation of the foramina. Only after careful dissection, usually of more than a single specimen, does the careful anatomist feel confident in discussing the relation of soft structures to the bones. Thus, the most careful dissection of the Percoid skull and the most perfect familiarity with its features and the relation of the bones to the soft structures would not enable one to describe the relation of the nerves and blood vessels to the skulls of *Polypterus*, *Amia*, *Accipenser*, any Selachian, an Eel (*Anguilla*), or a Cat Fish (*Gnidoglanis*), nor would the dissection of all but one of these enable one to interpret the foramina in the last with confidence. Again, the dissection of one Plagiostome, or, indeed, of many, would not enable one to state definitely the relationship of nerves and blood vessels to the cartilaginous cranium of a type not previously dissected.

It is, therefore, clearly a dangerous proceeding, and one likely to lead to very erroneous conclusions, for any palaeontologist, except in very exceptional instances, to write of any foramen that it "clearly transmitted" this or that nerve or vessel, or that "it could have transmitted none other" than this or that.

At the moment I can recall no instance among living fishes in which the emergent branches of the fifth and seventh nerves are not closely associated both on the inner and on the external surfaces of the skull, nor can I recall an instance where these nerve trunks do not, except the ophthalmicus superficialis and hyomandibular branches of the facial, emerge close to the cranial floor in the anterior part of the prootic region.

Almost invariably they leave the cranium either through the prootic bone or through a notch in its anterior margin; at times, all together through one single large common foramen, at others, through several small foramina closely gathered together. When more than one foramen is present, one can tell only by dissection which trunk or ramus occupied which foramen, for there is no constancy in their relation one to another.

There are several instances of the dangerous practice referred to throughout the two works under review; one instance only need be quoted, namely, the description of the "facialis chamber" in "Palaeoniscid B" which is epitomised, as it were, in Figure 19 on page 843 of the earlier paper. I have to confess that after years of study of the fish's skull, and after dissecting a reasonably representative series of the heads, I should be absolutely at a loss, on being presented with one so strange as this palaeoniscid, to interpret all the foramina. Dr. Watson does this with confidence, and even goes so far as to imply that the hyomandibular trunk of the facialis divides into two before emerging from the skull; or are we to understand that he finds in these foramina evidence that this fish had an extra mandibular branch of the facialis? The identification of the foramen for the patheticus in the bones of a fossil excites one's admiration, and at the same time it awakens one's suspicion. I have in very rare instances been able to find this foramen after carefully dissecting out the nerve. Its position is far from constant in the living fishes.

It is noticeable throughout Dr. Watson's work that he constantly identifies facialis and trigeminal foramina separated from one another. Having in mind the fundamental teleostoman characters of the fossils he is dealing with, one cannot but wonder whence comes the evidence on which this identification is based, and one feels that the practice results from the "tetrapod" frame of mind.

Turning now to the covering bones of the skull and dealing first of all with the dorsal aspect of *Chirolepis traill*. As restored by Watson, there is nothing in this skull to separate it from the modern teleostean type. True, one cannot point to any one skull amongst the moderns which exactly resembles it; on the other hand, a similar remark would apply to any one of the modern generic types; there are, outside the genus, no skulls whose dorsal pattern is precisely the same.

The dorsal pattern of *Chirolepis* is essentially similar to that of *Dactylopterus* (E, Fig. 1), but the latter has developed a supraoccipital between the parietals which is not present in the former. However, this feature cannot be regarded as of phylogenetic importance, for the allied scorpenid *Peristedion* has the supra-occipital covered by the parietals just as the fossil has. The presence of the occipital transverse limb of the lateral line canal system enables one to identify the post-occipital scutes in the two forms, whilst the post-temporal is similarly identified by the presence of the homologous canal in both

In thus identifying the bones by their contained lateral line canals, I follow a well-established practice. To quote Watson himself (1925, p. 820), "the passage of the main canal through the supraoccipital and intertemporal shows that these bones are homologous with the corresponding elements in the Osteolepids, or, at any rate, belong to the same row . . . " This quotation is particularly apt because it applies to the same bones in the scorpenid. In front of the post-occipital the canal passes across two bones before reaching the frontal, just as in the palaeoniscid These, by Watson's own criteria, will be homologous elements in the two forms.

The moulds of the neural crania of two Palaeoniscids which Watson depicts on page 834 and which he describes, present no features wherein they differ fundamentally from those of modern bony fishes. The outer wall of the so-called spiracular canal is in all probability really only the outer wall of the trigemino-facialis chamber. This is a very constant structure in the prootic region of the modern fish skulls, and, as in the palaeoniscid skulls, lies just below and in front of the hyomandibular articular facet. Its upper aperture probably transmitted the same nerves and vessels as in the modern forms, that is to say, the vena capitis lateralis, and the orbital artery passed to and fro through it whilst the hyomandibular branch of the facialis issued from its postero-superior opening, and the remainder of the trigemino-facialis trunks, except the palatine branch of the facial, issued antero-inferiorly.

It is unfortunate that Watson should have used such definite language in his description, for the whole of his interpretations and statements relative to the soft structures are entirely conjectural. On page 842 he declares quite confidently, and without any reservation, absolutely as though they were statements of fact, that various foramina transmitted various nerves and vessels. It is here that occurs the confusion relative to the branches of the facialis. He describes the hyomandibular branch as issuing through one foramen, and a mandibular as issuing with the palatine through another.

A more astonishing example of this independent uncontrolled identification is to be found on page 52 of the later of these two papers.

"Ventrally the outer margins of this bony plate (the 'Basisphenoid') are produced into long basipterygoid processes, which bear a depressed area for articulation with the palato-quadrate on the upper and anterior faces. The root of each basipterygoid process is perforated by a foramen which leads into a canal running upward and outward in the basisphenoid until it leads into a groove on the upper surfaces of the processus ascendens of the parasphenoid."

"From this canal a branch passes downward and inward to perforate the parasphenoid and open on the ventral surface of the skull. The main canal *must** have transmitted the palatine branch of the facial nerve, the branch being for a ramus pretrematicus, passing to the skin of the mouth, as Herrick has described in *Menidia*" (*Italics are mine.)

For comparison with this statement I quote Herrick (1899, p. 173) on *Menidia*· "A large bundle of communis fibres runs from the ventral surface of the geniculate ganglion, enters the same foramen as the truncus hyomandibularis, crosses the latter nerve and gives to it a considerable communis component, as already described. Immediately *after its emergence from the cranium* it divides into two approximately equal portions; one, the ramus palatinus, passes cephalad *along* (not *in*) the cranial wall under the origin of the m. adductor arcus palatini, the other, to which I have applied the name of ramus pretrematicus VII, turns directly ventrad along the caudal and inner face of that muscle and between it and the large pseudobranch, . . . " again not in a canal.

It is clear from this description that in no part of its length is the ramus palatinus facialis in *Menidia* enclosed in a bony canal, nor is the tiny ramus pretrematicus.

Herrick's description would lead one to infer that the canals described by Watson did *not* enclose the nerves.

The reference to *Menidia* is peculiar, because a comparison with *Amia* would have provided some resemblance. In this form the palatine nerve lies between the parasphenoid bone and the sphenoidal cartilage, and a similar position for the nerve in *Lepidosteus* has been described by Norris (1925, p. 371).

The parallel is, however, far from exact. In these forms the canal between bone and cartilage is reached by the nerve from without, and its posterior end is apparently much further forward than is the posterior end of the canal in Watson's drawing of *Cosmoptychius* No part of the canal for the palatine branch of the facialis in the two holostean forms lies in the basisphenoid region. In both cases the palatine nerve is accompanied by components of the glossopharyngeal nerve and by blood vessels.

Actually the most that can be said of the canal in question is that it is *possible* that it transmitted branches of the glossopharyngeal and facial nerves and *more* possibly blood vessels, but as to the source of the latter one would hardly be justified in hazarding a guess.

On page 848 of the earlier of the two papers Watson seriously discusses the form of the brain in an Osteolepid and in the Palaeoniscids, basing his whole discussion on internal casts of the neural crania. He says, "the cerebral hemispheres of *Osteolepis, if* we may judge from the character of the chamber in which they lay, were long and of considerable size. *In fact,* the brain, as a whole, *cannot* have differed very greatly from that of Ceratodus and an Amphibian"

Towards the end of the next paragraph we meet the following, relative to the brain of the Palaeoniscids· "It is probable that the *reduced cerebral hemispheres* imply that the sense of smell was no longer, as it is in all primitive fish, the chief agent in the recognition of food, and that the extravert type of cerebral hemisphere had already been introduced in them."

Like much else of the work, this is simply speculation, quite unsupported by factual evidence, and based on purely personal interpretation of the structures observed. In the same category is the statement on page 845 of the same work that "The seventh nerve arises by a single root, so far as can be seen from the skull, ..." One only wonders that our author does not tell us the relations of the nucleus of the facial nerve to that of the trigeminus!

Watson (1915, p. 848) says that in *Osteolepis* the outer wall of each olfactory capsule is perforated by a small circular external nostril, "its ventral surface by a triangular internal nostril, ..."

This again is entirely a question of interpretation, and not a statement of fact. (See postea p. 118).

Having in mind the licence which Watson has allowed himself in the interpretation of neurocranial structures, one cannot but view with suspicion his interpretations of the various fragmentary palates he attempts to restore.

At the outset one may point out that the identification of a notch at the anterior end of the palatal complex of *Nematoptychius* (fig. 26, p. 858) as being for the transmission of the mandibular and maxillary branches of the Vth nerve is obviously incorrect, at least in so far as concerns the mandibular ramus. The mandibular ramus must have passed down behind the gape of the mouth and close to the lower jaw joint. There is no reason to suppose that it took a course, entirely without parallel, far forward and then turned back.

Watson's figures 22, 23, and 24, represent palates which are subject to interpretation in terms of those of *Lepidosteus* and *Amia*. Although much fragmented, it appears unquestionable that that of *Eleonichthys aitkini* is the least distorted, and presents the bones in the nearest approach to their natural position. In the others, if Watson be correct in assigning them all to the same genus, the bones must be thrust from the midline and laterally compressed, or else the thin inner area of the palates has been lost. This appears to be supported by the condition present in the allied *Euryonotus crenatus* (1928, fig. 12, p. 62) and by the contours of both the palaeoniscid neural crania figured and described by Watson. These indicate that a relatively narrow interval was present between the hyomandibular articular facets on each side of skull.

A comparison of Watson's figure 23 (1925, p. 855) of the palate of *Eleonichthys aitkini* with the palate of the short-headed *Lepidosteus* leads to the belief, assuming that the illustration correctly depicts the fossil, that these two fishes are very similar. *E. aitkini* apparently possessed a true basipterygoid process articulating with one of the medial palatal bones. Since the process appears to have been in the same situation as that of *Lepidosteus* it is certainly not unreasonable to believe that it articulated with the homologous palatal element, that is to say, with the metapterygoid, and there appears to have been the same relatively extensive gap between the articulating bones and the hyomandibular behind in both forms. Apparently the whole palatal complex and its posterior mandibular suspensory components stood down well below the plane of the basis cranii, and, in the specimen illustrated, it has been displaced laterad and caudad. The bone which Watson identifies as the pterygoid is the mesopterygoid of *Lepidosteus* In the fossil fish it is more extensive than in the other and recalls that of *Polypterus*. The bones which Watson identifies as Palatines I, II, and III, and ectopterygoid, are certainly identifiable as an extensive, fragmented, palatine in front, and ectopterygoid behind. The little fragments identified as suprapterygoids IV and V are in all probability the fragmented metapterygoid. The unidentified fragment lying behind the ectopterygoid is conceivably portion of the quadrate.

This interpretation of the palate of *Eleonichthys* is not offered as a definite identification of its elements but as an indication that, on the evidence before us, it is possible to interpret it in harmony with already completely known fish palates, and because it is undesirable whilst such an interpretation is possible to create new palatal types on such fragmentary evidence as these crushed and distorted palates provide.

One cannot conclude this review of these two papers without commenting on Watson's identification of the basipterygoid process in several of the fishes described.

The basipterygoid process is an ossification of the para- or immediately pre-pituitary region of the cartilaginous basis cranii, and is a process of the basisphenoid bone.

Nowhere among the living fishes do we find a basipterygoid process which conforms completely to the above definition. In *Lepidosteus*, however, there is an ossification of the correct region of the basis cranii, but the ossification is by an extension forward of the prootic bone, not the basisphenoid.

Kesteven (1926, p. 121) suggested that we should regard as completely homologous, bones which ossify in precisely similar regions of the primary chondrocranium, even though they may not develop from similar centres of ossification, proposing at that time to designate those which develop from the usual centre of ossification, "determinate"; and those which develop by extension from the centre of ossification of a contiguous bone, "predeterminate."

Applying this principle in the present instance we may accept the identification of the basipterygoid process in *Lepidosteus* It is truly a basipterygoid process, but is a predeterminate form thereof.

Comparison of *Lepidosteus* with Watson's illustration of the fragmented palate of *Eleonichthys aitkini* leads one to accept without reservation the identification of a basipterygoid process immediately medial to the little palatal fragment labelled S.Pt.IV. It is also very probable that the parasphenoid extended much further back than Watson's interpretation allows.

In the case of *E. binneyi*, however, it is clear that the tubercle which is identified as the basipterygoid is placed a long way too far forward to be that structure; there can be little doubt that this tubercle is actually antorbital in situation.

In *Polypterus* and quite a number of the Teleostei there is a projection of the parasphenoid below the basis cranii in the region in which the basipterygoid process is found. This is a fundamentally different structure to the true basipterygoid process. It is not developed endochondrally from the primordial basis cranii.

It is to be observed that in *Lepidosteus*, in which the true process is developed, there is related to its underside a spur of the parasphenoid. In *Polypterus* and the other examples mentioned there is no cartilaginous or endochondral bony process related to the parasphenoid spur.

In *Cosmoptychius striatus* (1928, p. 52) the basipterygoid process is correctly identified by Watson as a process of the basisphenoid (Watson, 1926).

Watson asserts that *Dipterus valenciennesi* presents so many features which resembled those of the contemporary Osteolepids that the two groups (Dipnoi and Osteolepida) "arose from a common ancestor not much earlier in date," and he continues, "it is from this hypothetical fish that I believe the Amphibia to have risen. The evidence on which this view is founded is most convincingly presented by a comparison of the structures of the skeleton, of the body form, and movements, and of the mode of life, in an Osteolepid and an Embolomerous amphibian. In order to secure the materials for such a comparison I have been forced to investigate the osteolepid structure anew . . . ." (p. 195).

Dr. Watson is certainly ingenuous; he does not hesitate to admit that he was already convinced before studying them that, if the fossil fish were studied, evidence in support of his preconceived theory of the evolution of the Amphibia would be found in their structure.

It was apparently this mental attitude which prompted the following paragraph. "The exoccipitals in the Osteolepida reach up to a well-developed supraoccipital, which in *Osteolepis stretches forward over the whole of the hind brain,* as it does in the Embolomeri. The otic capsule forms a paroccipital process which supports the tabula, and may or may not be in contact with the skull roof for the whole of its length, precisely as in the Amphibia. As in them, the anterior part of the brain lies in a cavity in the upper part of a thick interorbital septum whose lower edge is the parasphenoid." Watson persistently makes the error of designating the parotic process "paroccipital" The paroccipital process lies ventrally to the otic capsule, the parotic lies dorsolaterally to it

"The basisphenoid in both fish and Amphibia has definite basipterygoid processes with which the epipterygoids articulate."

As was the case in the last papers reviewed, much of the apparent statement of fact in these two paragraphs is largely interpretation. In the previous paragraph to that quoted, it is stated that the osteolepid brain case "*is not divided into separate bones in any known specimens*" Yet we are told that this osteolepid brain case resembles the Embolomeri *because its component bones occupy certain areas.*

Examination of his illustrations discovers that the parotic process of the Embolomeri is infinitely better developed than that of the osteolepids, in which it is essentially similar to that of almost any typical acanthopterygian percoid skull. In these forms it has not been dignified by separate designation or definition. In the Embolomeri, if they be all similar to that of *Orthosaurus pachycephalus,* the parotic processes are extensive and recall those of certain of the reptiles and modern amphibians.

The statement relative to the situation of the anterior part of the brain is absolutely without any foundation in fact; on the contrary, remembering that these were fossil fishes such evidence as may be obtained by the examination of the cranial cavities of the modern ganoids and teleosts, and consideration of their casts relative to the form and situation of the contained brains, suggests that the forebrain did not extend appreciably past the well-defined temporal fossa of perfectly typical teleost outline which Watson depicted in the Palaeoniscid in figure 20 of the 1925 paper, nor much anterior to the typical trigemino-facialis chamber illustrated in the top drawing of figure 78 of the communication under review.

Not only is this so, but his own descriptions and illustrations belie his homologies. It should surely have been obvious that the structures which he labels basipterygoid processes in the two reconstructions of fish crania illustrated in his fig. 4 could not be regarded as basipterygoid processes.

In the *Baphetes*, on the other hand, there is obviously a typical basipterygoid process of the basisphenoid essentially, one might almost say precisely, similar to that of many reptiles. In the *Eusthenopteron* a critical examination of Bryant's description and illustration of the orbitosphenoid must surely satisfy one that it is the posterolateral corner of a relatively normal ethmosphenoidal ossification which is here identified as a basipterygoid process.

One must also take exception to Watson's assumption that the metapterygoid of the Osteolepida is the homologue of the epipterygoid of the Embolomeri (vide postea, pp. 119-121).

This assumed homology rests only on his further assumption that certain branches of the fifth nerve passed in certain relation to the dorsal margin of the bone. Even if we grant his assumption, as to the spatial relations of the bone and the branches of the nerve, the homology is by no means proven. Kesteven demonstrated quite conclusively that the relation of the branches of the fifth nerve to homologous bones is variable, and unreliable as a definitive feature in determining homologies (Kesteven, 1926).

As a matter of fact, this homology is so far fetched that it could only have been suggested by one in search of evidence in support of a preconceived theory; it would be amusing if it were not regrettable.

Ridewood, in 1904, described the neural crania of a number of more or less abnormal teleostean forms, and several of his illustrations have been reproduced by Gregory (1933), who gives in addition illustrations of a number and a wide range of normal crania. It is suggested that if Watson's illustrations of the neural cranium of *Osteolepis* and Bryant's *Eusthenopteron* be compared with these and with figure 4 of this communication, such a comparison must convince the unbiassed student that the fossil neurocrania are readily interpretable in terms of that of the modern fishes. The resemblance is essentially to the fishes. One notes that the parasphenoid is missing.

Watson writes (p. 234), "The neural cranium of the osteolepids was first, though quite inadequately, described by Rohon; later again misleadingly, by myself and H. Day and by E. A. Anderson; and finally more successfully by W. L. Bryant. Dr. Bryant's description is, as Dr. Stensio informs me, and I have been able to confirm, from an examination of the original material, inaccurate in certain respects . . . ."

Notwithstanding all this difficulty and divergence of interpretation, Dr. Watson uses his latest interpretation with complete confidence to supply evidence as to the evolution of the Amphibia. He tells us that the arguments of his communication rest upon the structures of the Embolomerous Amphibia and of the Osteolepid fish. As a matter of actual fact, then, the whole of his argument on their cranial structure in support of the crossopterygian origin of the Amphibia, rests largely on assumed structures which may or may not have been present in the neurocrania of *Osteolepis* and *Eusthenopteron*, and on the similarity of the dermal covering of the skulls.

Dr. Watson's three drawings of the lateral view of the neural crania are misleading, and almost partake of the nature of "special pleading." His other illustrations show very plainly that these neural crania in a dorsal or ventral view would have shown even less resemblance than do these lateral views.

The similarity of the dorsal dermal pattern of *Cheirolepis* to that of modern Acanthopterygii has been discussed previously. Gregory (1933) has reproduced Watson's illustration of this and of the three illustrated on page 197 of the work. These may be conveniently compared with the dorsal pattern of the moderns illustrated on the later pages of Gregory's work.

At the same time it may be pointed out that if similarity of dorsal dermal pattern may be accepted as evidence of genetic relationship, then the converse should be true.

A classification of the modern fishes based on such a premise would indeed lead to a chaotic grouping of the living forms.

Watson writes (p. 245), "A comparison with *Macropoma* (one of the Coelacanth fish) shows quite clearly that the pituitary fossa lay within the basisphenoid between the basipterygoid processes, and the position of the pineal foramen confirms the view that the thalamencephalon lay in the hinder parts of the anterior section of the neural cranium." There is no certainty that a pineal foramen is present. Many modern fishes exhibit deficiencies in the dorsal roof, in the position of a possible pineal foramen, but these are not of that character.

Quite apart from the fact that the basisphenoid bone of *Macropoma* differs markedly from that of the *Osteolepida*, as restored by Watson (and there is no certainty that the bone in *Macropoma* is a basisphenoid at all), Watson has himself advanced the strongest evidence against the possibility of the brain extending into the "anterior section of the neural cranium."

He has advanced evidence that there is a joint between the two "sections" of the "neural cranium," and that the joint functioned as such, that is to say, he believes that there was actual movement about this joint.

It appears highly improbable that the brain should have been subjected to stress and strain by lying across a joint. There is no doubt that the joint between the dorsal derm bones in the Dinosaur skull (with which Watson compares it) lies entirely in front of the brain, as does that of the parrot's skull.

The Braincase of the Carboniferous Crossopterygian Megalichthys nitidus, by A. S. Romer.

The neurocranium has already been discussed, but further comments are called for. In a later paper (1941) he has described the hyomandibular of this fish in detail. His specimen indicates that the bone was binarticulate and he was of the opinion that this was an unique feature. He states (p. 147), "in all fish hitherto known, the hyomandibular has but a single attachment." This is quite erroneous, the hyomandibular bones of recent fishes present one, two or three distinct and separated articular facets. Kesteven (1926, p. 208) proposed the terms mon-, bin- and trin-articulate as descriptive of both the bone and the type of articulation. It is possible that this hyomandibular was attached to the skull in the same manner as the binarticulate types amongst the recent fish. It has not yet been found actually in place.

It is believed by Romer and others that the two articulations of the bone were placed above one another. Whilst the two depressions present on the side wall of the skull justify the belief, it is possible that the lower really gave attachment to the anterior end of the branchial skeleton, it is certainly in the position of such facets on numbers of the recent fish.

There are quite important factors which give support to this suggestion. First, it seems reasonable to assume that the hyomandibular was, at least, as firmly bound to the opercular bones and cheek plates as in living archaic fishes. Therefore, if the bone was articulated to the skull at two points, one above the other, then all these bones must have been so firmly fixed that the movements of respiration would have been impossible.

Neither abduction, adduction nor rotation would have been possible about the hyomandibulo-cranial joint, but on the other hand, the well-developed articular heads of the bone indicate a functional joint. If Romer's illustration of the hyomandibular bone is correct, then, with the two facets in place in the depressions he illustrates on the skull, the shaft of the bone would have, apparently, been directed upwards and backwards. If, as in other binarticulate bones, the two joints were placed at the same level, one behind the other, the direction of the bone would have been normal, and, of course, the normal movements of respiration could have taken place.

Romer writes that comparison with *Ceratodus* suggests that "two small tubers" on the ventro-lateral surface of the otic capsule "afford origin for branchial levator muscles."

The facts are that in *Ceratodus* the levator branchii muscles arise from the underside of the cartilaginous roof of the branchial fossa and from the perfectly smooth surface of that ceiling (Kesteven, 1944, pp. 140-141). It is very exceptional for muscles to arise from tubercles or tuberosities on the skull of any of the fishes. The characteristic condition is that they arise from flat surfaces, and from fossae separated by flanges or ridges, to which the muscles, commonly, are not attached.

In the present instance it is evident that Romer did not make an examination of the actual conditions in *Ceratodus*. Had he done so his dissection would have prevented him from making such a comparison

The whole of the arguments of Romer and others in the attempt to establish similarities between the suspensorium of the Crossopterygians and that of the Tetrapods, are discounted by the fact that in the Fishes, suspension is effected by the hyomandibular, which is placed between the quadrate and the skull. The Chimeroids are the only fish in which the quadrate is attached directly to the skull. Romer discusses the attachments of the quadrate to the skull, and the question whether they are primary or secondary. The weight of embryological evidence was accepted, two or three decades ago, as proving them to be secondary, and this has not, I believe, been questioned since. All the evidence in question also indicates that no part of the hyoid has entered into the formation of the attachment of the quadrate. Therefore, in the presence of a hyomandibular, we are in the presence of a fundamentally important feature which distinguishes the whole of the rest of the fishes from the Chimeroids as well as from the Lung fishes and the rest of the tetrapods.

It should be noted that the whole of the arguments are directed towards establishing similarities and homologies between Crossopterygians and tetrapods which are obviously and admittedly present as between Dipnoans and Tetrapods. Although cognizant of this, palaeontologists have failed to recognise its importance because the palate of the Dipnoans is so peculiarly specialised.

Romer writes, "it is unquestionable that the crossopterygians and lung fishes are allied stocks But comparison of their endocranial structures is difficult. Part of this is due to marked difference in jaw structure and articulations. But further difficulties are due to the fact that living lung fishes have surely departed widely from the ancestral type in braincase structure, as they are known to have done in the case of the dermal skeleton."

There is no evidence that the braincase of the modern Dipnoans has departed in any important detail from that of the early forms, or from the ancestral type. The modification of the dermal shield cannot be accepted as evidence of any such change.

On the Structure of the Snout of the Crossopterygians and Lower Gnathostomes in General, E Jarvik (1942).

Jarvik describes the snouts of three crossopterygian species in great detail The work is based on reconstructions from serially sectioned material, and the correlation of features presented in several specimens There is every reason to believe that he has presented us with correct descriptions and illustrations of the three snouts.

Jarvik has no doubt that both the rhipidistian species illustrated were choanate, and at first sight his descriptions and illustrations of *Eusthenopteron*, at least, appear convincing A more critical examination of his evidence, however, leaves one very much in doubt. The specimen is undoubtedly portion of a fish, and the description is confined to bony parts In all recent ganoids and in a very large number of the modern fishes there is much cartilage related to the ethmosphenoidal ossifications In the absence of this cartilage the nasal capsules of quite a few forms would appear to open ventrally. Also there is a gap, in the situation of the "internal naris" in the palate of *Eusthenopteron*, between the palatal bones of many recent fish. This gap is made good in the living fish by cartilage and/or connective tissue. It must not be forgotten that the surviving ganoids are not choanate These recent ganoids are really the only factual evidence we have as to what the structure of the ganoids was.

After the most detailed "restoration" of the constitution and distribution of the cranial nerves and other soft structures in relation to the snouts of *Porolepis* and *Eusthenopteron*, Jarvik concludes that the Urodeles are derived from the Porolepiformes, and the Anura from the Osteolepiformes.

If Jarvik's restorations might be accepted as evidence, there is no doubt that they would support his contention, but remembering that the neurocrania are undoubtedly those of fish, and present most of the characters of fish neurocrania generally, there is no doubt that any competent anatomist could "restore" the distribution of the cranial nerves and location of the main blood vessels in accord with the general pattern of the fishes just as convincingly, and with, perhaps, more justification. His contribution to factual evidence is his careful description and illustration of the three snouts. All his restorations are merely reiterations of his conviction that they exhibit amphibian characteristics. The evidence supporting his conclusion as to the derivation of the two recent amphibian groups resolves itself into the facts that the nasal capsules of the Porolepiformes are widely separated, whilst those of the Osteolepiformes are separated by only a nasal septum.

Jarvik overlooks, or neglects, the fact that in some of the Urodela the nasal capsules are separated by only a septum as in the majority of the Anura, whilst in some of the latter the capsules are separated as in the majority of the Urodela. These facts throw very grave doubts on the verity of his conclusions.

It might, conceivably, be suggested that since the capsular conditions cited by Jarvik are, in the main, characteristic of each of the two classes, those which depart therefrom are degenerate, or otherwise specialised. As a defence of his thesis, this argument must defeat itself. If it be granted that either form may be derived from the other directly, by degeneration or otherwise, then, wherever it occurs it may have been so derived.

I have repeatedly insisted, both for myself and others, that because none of our problems in evolution are, as yet, capable of mathematical presentation and proof, we are not justified in stating any of our opinions or conclusions dogmatically or, in effect, writing Q E.D. after any of them. I may, therefore, perhaps be permitted to record a protest against the presentation of opinions ("restorations") as though they were facts. This practice imposes upon readers the necessity of being constantly on the alert, lest they be misled into accepting those opinions as factual evidence, and calls for an irksome degree of concentration in the reading.

THE HOMOLOGY OF THE CROSSOPTERYGIAN METAPTERYGOID BONE.

An extraordinary confusion has resulted from the application of the designation "epipterygoid" to a certain bone in the wall of the cranial cavity of fossil amphibians and on the palatoquadrate of certain fossil fish Save-Soderbergh (1936, p. 145) wrote:

"The extension of the epipterygoid ossification in *Lyrocephalus* to include both basal, ascending and otic processes of the palatoquadrate throws a new light on the nature of the so-called metapterygoid of the Coelacanthids. It has already been shown by Stensio that this *metapterygoid corresponds* to the *processus basalis, ascendens* and *oticus* of the palatoquadrate in Dipnoi and Tetrapods. We are now able to go further and say that the so-called metapterygoid of the Coelacanthids is the exact equivalent of a well-ossified *epipterygoid* of a Labyrinthodont. And even if it is probable that the bone discussed arose independently in the two groups by fragmentation of a continuous palatoquadrate ossification, it is evident: (1) that the bone discussed of the Coelacanthids is much more closely comparable to the epipterygoid of the Tetrapods than the metapterygoid of the Actinopterygii; (2) that the presence of such *exactly comparable* bones is evidently due to very closely *comparable mechanical* conditions in the two groups, indicating a close relationship. Accordingly, it seems more correct that the bone discussed be called the epipterygoid also in the Coelacanthids."

So much of this quotation is so utterly at variance with generally accepted belief, that the absence of argument or evidence in support of its astonishing statements makes one wonder whether it is not entirely due to careless terminological inexactitude. It cannot, however, be dismissed so lightly. To begin with, his so-called epipterygoid (cpt. fig. 5) is *probably* a prootic ossification, and *possibly* a predeterminate alisphenoid bone.

It will have been noted that in the above quotation he states that the epipterygoid ossification of *Lyrocephalus* includes not only the ascending process, but all three processes. He then states that the metepterygoid of Coelacanths has been shown by Stensiö to correspond to all three processes of the palatoquadrate of Dipnoi and Tetrapods, and next states that this metepterygoid is the "exact equivalent" of an epipterygoid in a Labyrinthodont. This is, in effect, stating that the ascending process of the quadrate in this Labyrinthodont is homologous with all three processes in the Dipnoi and Tetrapods. But the Labyrinthodont is itself a Tetrapod!

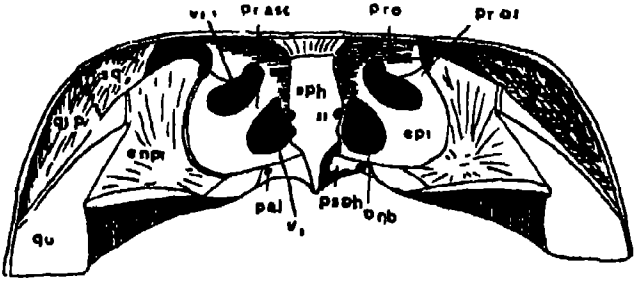


Fig 5.—*Lyrocephalus euri*. Neurocranium and palatoquadrate, with the anterior part of the skull cut away (from Säve-Söderbergh, 1936).

The exact comparison of the quotation is based upon the supposed participation of the metapterygoid in the formation of a cavum epiptericum in the fish, and on the assumption that in the fishes in question the palatoquadrate was suspended from the skull by the metepterygoid alone.

The discovery of the complete and perfectly typical hyomandibular in *Megalichthys* and in *Latimeria* completely disposes the latter assumption, and with it the "closely comparable mechanical conditions."

It is, of course, well known that the palatoquadrate is attached posteriorly in all amphibians, except the Coecilians, by basal, otic and ascending processes. In the Coecilians only the ascending process is present. It is equally well known that the processus ascendens is present in embryonic stages, of all reptiles, and persists as an independent "epipterygoid" bone in Lacertilia, Rhyncocephalia and some few other reptiles.

Unfortunately, this bone was confused with the alisphenoid bone of the Crocodilia and Cynodontia, so that this and the alisphenoid bone of some amphibians came to be designated epipterygoid. Kesteven (1918, 1926 and 1941) pointed out that whilst the bone in the Cynodonts was pretty certainly homologous with the alisphenoid of the Mammalia it was not homologous with the epipterygoid bone.

Be that as it may, the fact is that any bone in the side wall of the cranial cavity of an amphibian or a reptile may be designated "epipterygoid" only if it be deemed to be homologous with the processus ascendens quadrati. Säve-Soderbergh is not alone in describing on the palatoquadrate of fishes and in the side wall of the cranial cavity of certain amphibians an "epipterygoid bone"; a processus ascendens quadrati; which has, attached to it, ascending, basal and otic processes.

In view of the presence of the ascending process as one of the attachments of the palatoquadrate in all recent amphibians and in so many reptiles, we are surely simply compelled to regard it as an inherited feature. Further, since all three processes are present in all recent Urodela, Anura and Dipnoi, they, too, must be regarded as having been inherited from the common ancestor. If these be deemed reasonable assumptions, then it would seem to follow that primitive amphibians also had these same three processes. If not, whence came they in all the recent forms?

Whatever be the answer to the last question it is quite wrong to designate any structure the epipterygoid bone, unless it be equated with the processus ascendens quadrati.

Stensio, Save-Soderbergh and Watson all fail to compare the palatoquadrate arch of the Crossopterygians with those of fishes The comparison is attempted here, and since illustrations convey shape and relations better than words the palato-quadrate arches of *Wimania, Macropoma, Lepidosteus, Salmo, Epinephalus* and *Latimeria* are pictured below (Fig. 6). It is surely quite clear that the only differences between these specimens are those due only to variation in the length and width of the component bones The close resemblance of Smith's description and illustrations of the bones in *Latimeria* to those of the fossil forms justifies confidence in the correctness of the descriptions of the palaeontologists These are fairly certainly, not coincidental resemblances. The bones are the same in the fossils and in the living forms.

It may be concluded that the metapterygoid bone of the Crossopterygians is not merely homologous with the bone of the same name in the recent fish, it *is* that bone.

THE PALATO-PTERYGOID PORTION OF THE QUADRATO-PALATAL ARCH

Romer (1937) offered an exceedingly interesting "working hypothesis" which, he says, is far more consistent with known palaeontological facts than those based primarily on embryology, which are now current. It is that in the primitive gnathostome the upper end of the maxillary and upper ends of the rest of the arches were fused to the skull.

This suggestion offers a very simple explanation for, and is supported by the cartilaginous continuity of, the anterior end of the palatoquadrate and ethmoid, which has been observed in some Elasmobranchs and Teleostomes, most Urodeles and all Anurans

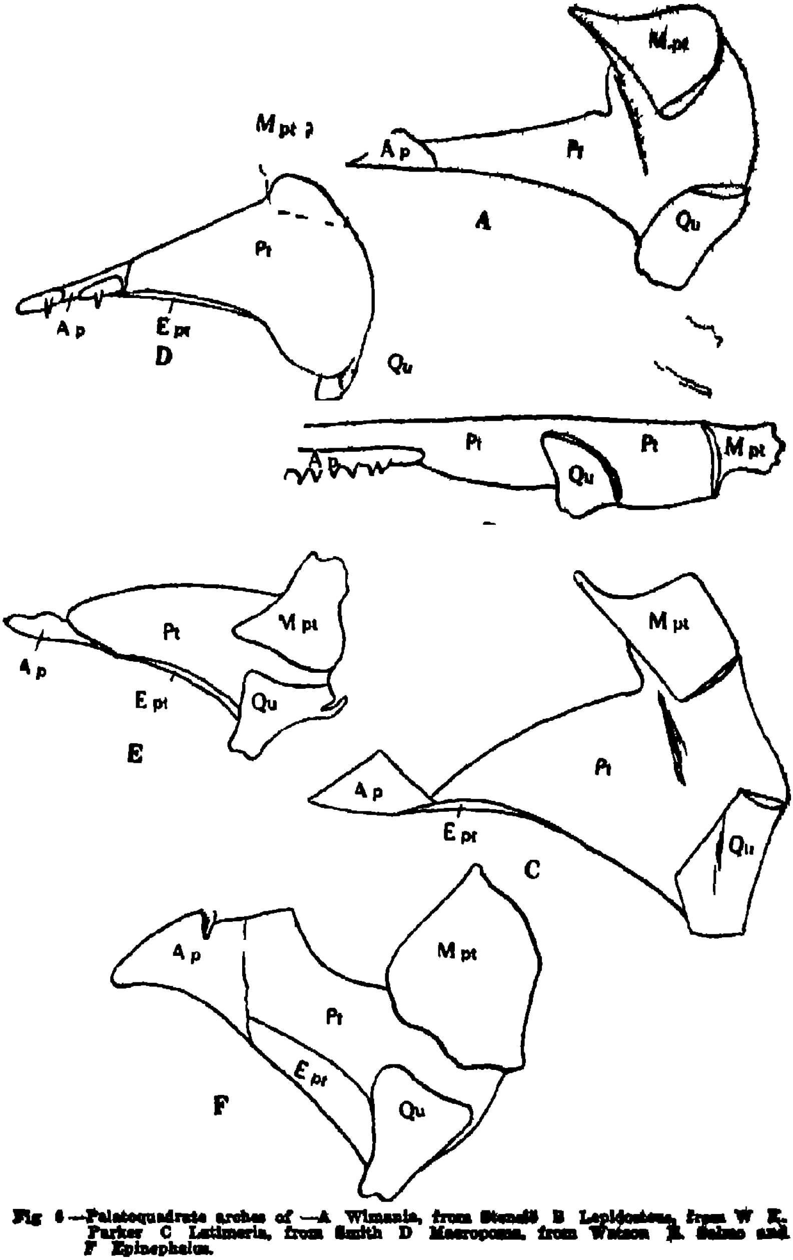


Fig 6—Palatoquadrate arches of —A Wimania, from Stensiö B Lepidosteus, from W K. Parker C Latimeria, from Smith D Macropoma, from Watson E Salmo and F Epinephelus.

It also offers a very simple explanation for the origin of the palato-pterygoid portion of the arch, and one more understandable than that generally accepted at present. The present belief is that the upper end of the arch is at the attachment to the skull behind, and the pterygoid process is deemed to be a secondary anterior growth. If Romer's suggestion is correct, then the upper end of the arch must be the anterior end, so commonly attached to the ethmoid. The palato-pterygoid portion would be regarded as the body of the original half-arch, and the quadrate and its processes of attachment would all be deemed to be secondary developments, in response to the mechanical need of firm fixation of the jaw joint, and the efficient development of the joint itself.

This explanation of the origin of the anterior portion of the palato-quadrate arch, granted that Romer's suggestion is correct, is not only a very simple one but it is supported by the mechanical factors which may reasonably be thought to have been operating. The current theory is based entirely on embryological evidence and is devoid of any mechanical explanation; nor does it explain why the anterior end of the process is so commonly continuous with the ethmoid.

It may be said that in a study of the cephalic musculature of the Elasmobranchii, the serial homology of the muscles of the branchial, hyoid and mandibular arches can only be understood on the assumption that the palato-pterygoid process is, itself, the upper half of the Maxillo-mandibular arch. (*Vide* Vetter 1874, 1878, Edgeworth 1935, Lightoller 1939, Kesteven 1942-45.)

Section III

The most convincing presentations of the case for the crossopterygian origin of the Tetrapods were the earlier contributions. These were based entirely upon the various features wherein the fossils clearly resembled the primitive amphibians. The most important evidence was that provided by the Upper Devonian fish, *Eusthenopteron* In fact, it is almost true to say that the whole case rested upon the marked similarity of certain features in the dermal shield and palate of this fish to those of the Embolomeri, primitive amphibians from the Coal Measures. The case has, since then, been further strengthened by the resemblances of the Ichthyostegidae, Upper Devonian amphibians, to *Eusthenopteron* and some of the other Devonian and Carboniferous Crossopterygians.

Although palaeontologists have interpreted the better preserved neurocrania of these fossil fishes as supporting the crossopterygian origin of the tetrapods, the fact remains that these are essentially the neurocrania of fish, and, as a matter of fact, bear very little resemblance to those of the primitive, fossil, amphibians.

Although the mutual resemblances of the dermal shields and palates of the primitive fishes and amphibians does justify a belief in the accepted theory, the evidence is far from convincing. A critical examination of the facts available leads to the belief that the dawn of the Tetrapoda antedated the appearance of the Crossopterygians and took place in Lower Devonian times or earlier.

The earliest known Crossopterygian is apparently *Porolepis*, which appeared in the Lower Devonian. Unfortunately, nothing is known of its palate beyond the fact that the parasphenoid bone extended far forward, as in other members of the Rhipidistia, and that there was a tooth-bearing premaxilla. The evidence is scanty, but, as far as it goes, it suggests very strongly that the palate was similar to that of the Crossopterygia generally.

The Dipnoi and the Ichthyostegidae appear together, in point of time, in the Upper Devonian. There is no doubt that the latter were tetrapods, that in fact they were amphibians. There is no reason to believe that the Devonian dipnoans differed in any important respect from the recent forms, and the work of Kesteven (1931, a and b, 1942-45) and Kerr (1932) should have removed any doubt that they are primitive amphibians also.

There were, then, two distinct tetrapod types existing in Devonian times, and they must have been derived from an earlier ancestor. There is a general agreement that these two primitive tetrapods were derived from a common stock. It is obvious that the Ichthyostegids and the Dipnoans cannot have been derived from contemporaneous Crossopterygians, and, therefore, notwithstanding the many features of similarity, we must look elsewhere for the common ancestor of these two earliest tetrapods

Before proceeding further it would be well to briefly review the features of similarity between the Ichthyostegids and the Dipnoans.

Säve-Soderbergh (1932, p. 98) wrote:—"in certain characters *Dipterus* seems to be more nearly related to the Ichthyostegids than are the Crossopterygians Thus, its dermosphenotic seems to have fused with the postorbital; on the right of the specimen figured the supratemporal has fused with the intertemporal, and finally there is is an unpaired central parietal, whereas in Crossopterygians there are only paired parietal elements" He then gives details of certain differences, and, later, continues. "There is, however, also in the palate one feature in common to the Dipnoans and Ichthyostegids, but not found in the Crossopterygians, viz, the median suture between the anterior parts of the entopterygoids."

The position of the two nares is another feature wherein the Ichthyostegids resemble the Dipnoans It may be that somewhat similar nares are present in some Crossopterygians.

There is yet another, and very important, feature in which the two tetrapods both differed from the Crossopterygians This is the absence of the hyomandibular as a component of the suspensorium. Although overlooked or neglected by palaeontologists, this is a feature wherein the Dipnoi, and presumably the Ichthyostegids, present a distinct and fundamental *advance* on the crossopterygian condition.

It is difficult to believe that these features of similarity could have arisen independently in the two tetrapods; therefore, it would seem that if either was derived from a crossopterygian ancestry, both must have been. Since all known Crossopterygians had hyoid suspension, it seems improbable that the tetrapods were derived directly from them.

The undoubted resemblance in the number and arrangement of the bones in the palate must be accounted for on the assumption that all three derived the palate from a common ancestor.

The resemblance of the palate of the Dipnoans to that of the Ichthyostegids is not obvious, but is recognisable once it is realised that the differences are due to the *absence* of bones from the former. It is generally agreed that the peculiar character of the Dipnoan palate is due to extreme specialisation, which has resulted in the *loss* of the bones related to the palato-pterygoid portion of the maxillary arch. The bones which remain differ from the corresponding elements in the primitive amphibian palates, in size only, *not* in their relations to one another or to the base of the cranium (Fig. 7). The essential similarity of these bones is only partly disguised by the peculiar teeth on those of the Dipnoans, and this difference in the teeth should not be deemed of phylogenetic importance because we observe equally marked differences in the teeth of, relatively closely related Elasmobranchs.

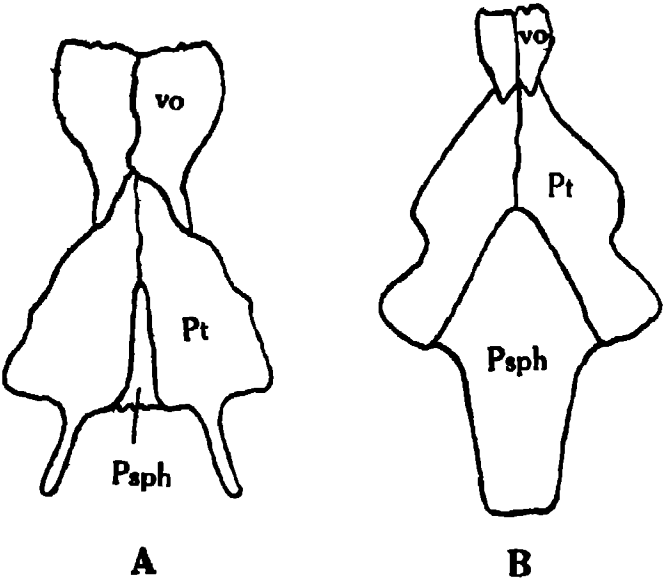


Fig. 7.—Two Dipnoan palates.

The important concept here is that the differences in the lateral parts of the palates is due to loss of bones from that of the Dipnoans. It will be observed that this is referred to as a concept, not as a fact; it is based upon an assumption. If that assumption is accepted as reasonable, then, one is emboldened to say that in their cranial osteology, the Ichthyostegids may almost be regarded as Dipnoans which have not lost the lateral elements of the palate, and in which the parasphenoid bone has undergone a further reduction towards that complete loss seen in the Sauria.

The reduction of the parasphenoid bone in the Embolomeri and the Ichthyostegidae is another fact which makes it difficult to believe that the Tetrapods have been derived from the Crossopterygians.

The Tetrapods can only be derived from the Crossopterygians through these two primitive groups of Amphibians. The whole of the arguments in favour of such an ancestry is centred on their mutual resemblances. In the reduction of the parasphenoid bone these two groups have as it were, progressed *beyond* the amphibian condition. In all other amphibians this bone is very extensive, covering nearly the whole of the ventrum of the neurocranium, and extending far forward beneath the ethmoid region

If the Amphibians generally have been derived from the Crossopterygians through either of these two groups of primitive Amphibians then there must have been in all these others a return to the primitive fish condition in the size and importance of this bone as the covering of the base of the neurocranium Such a complete reversal in an evolutionary change would be without parallel and be difficult to explain or understand

Another fact which should not be neglected in this connection is that all four groups of the Stegocephalians are represented in Carboniferous rocks and not only is this so but a primitive reptilian group, the Cotylosauria are also of Carboniferous age

There is little room for doubt that the Embolomeri and the Ichthyostegids were the amphibian group from which the Cotylosaurs were derived it is difficult to believe that they also gave rise to the very dissimilar Stegocephalians

After a very extended survey of the cephalic musculature I could find no evidence either in the embryology or the adult anatomy, of any teleostome ancestry for that of the Tetrapods On the contrary it was found possible to derive it through the branchiate Amphibians the Dipnoans and Holocephali directly from the elasmobranchian condition (Kesteven 1942-45) Lightoller was of the same opinion (1939)

To assert that the resemblances of all vertebrate palates are such that — they must have been derived from a common ancestor — would be to make one of those dogmatic statements which I have said we are not justified in making But so general is the agreement on this matter that the statement would probably go unchallenged

I have recently reviewed the arrangement of the bones in the palates throughout the whole of the various classes of the vertebrates and found reason to believe that those of the tetrapods and the bony fishes were derived from an ancestry common to both and that the former was not necessarily derived from the latter (Kesteven 1947)

Reviewing the scanty evidence available it certainly seems to point to the existence in Lower Devonian or earlier times of some as yet undiscovered ancestral form from which the Dipnoi Ichthyostegidae and the Embolomeri were derived and which itself was derived from an earlier ancestor common to it and the Crossopterygians

This same scanty evidence also justifies the expectation that when discovered the Lower Devonian or Silurian protetrapod will be found to have a palate made up of the number of bones found in the amphibian palates with a large parasphenoid bone and with the quadrate portion of the arch attached directly to the neurocranium without any hyoid component in the suspension of the upper jaw arch

From this protetrapod we may be permitted to believe that three distinct lines of evolution originated The first was that leading to and ending at the Dipnoi The second gave rise to the Stegocepha liana, and Euamphibia generally. The third gave origin to the Sauramphibia (Ichthyostegidae and Embolomeri), which, as the name suggests, gave rise to the Sauria.

THE DIPNOI

Living Dipnoi are the most primitive amphibians known to us. Although they possess a few very characteristic fish features, they are very definitely not fish. Kellicot (1905) was the first investigator to carry out detailed work and to conclude from it that the Dipnoi are very closely allied to the Amphibia. In 1931 I published two papers in which the many points of resemblance of the Dipnoi to the Amphibia were detailed. In the following year, and quite independently, Kerr (1932) referred to a number of those features and added a few more, and he concluded (p 421) that they constituted "together an assemblage of features which demonstrates irrefutably, the close relationship with the Amphibia *and the distinctness from the fishes*" Dakin (1931) recorded that the body fluid of *Ceratodus* differed fundamentally from that of the fishes, and resembled that of the Amphibians. Recent investigations into the adult form (Kesteven, 1942-45) of the cephalic musculature, and its development (Edgeworth, 1923) in *Ceratodus* and other lung fishes reveals this to be very primitive. In the case of one set of muscles only was any resemblance found to the bony fishes, in six instances the resemblance is to the Amphibians. For the rest, the resemblance is to the Elasmobranchs

Elliot Smith (1908) has two paragraphs which are of particular interest to the present discussion, in the summary of his description of the fore-brain of *Lepidosiren*

"(1) If the features of the brain in the Dipnoi be considered as a whole, they will be found to approximate *much* more nearly to those of the Amphibia than to those of any other vertebrate.

"(9) The high state of development of the cerebral hemisphere in the Dipnoi gives us two alternatives from which to choose as to the relative positions of the Amphibians and the Dipnoi:—either the Amphibian hemisphere has passed through a state corresponding to that of the Dipnoi and has then undergone a secondary retrograde change, *or the Dipnoi are nearer to the main stream, which has led to the origin of the Amniotes*" (The italics are mine)

Confining himself, largely, to the dermal covering bones, Stensio expressed the opinion that—"The study of the Coelacanths seems to help in throwing fresh light on the relationship of the Dipnoi and the Crossopterygians. According to our present knowledge, the latter, or forms very nearly allied to them, must be considered as ancestors to the Dipnoans, and must consequently be grouped close together with them from a systematic point of view *There is no justification at all for separating the Dipnoi from the Teleostomes, as has hitherto often been done.*" (The italics are mine.) This statement is demonstrably quite wrong.

It is submitted that the tabulation below is, as Kerr said, an *irrefutable* demonstration of the close relationship of the Dipnoi and the Amphibia It is further submitted that such a preponderance of evidence of resemblances must be accepted as proving that the living Dipnoi are actually primitive Amphibians

It may be pointed out that whilst there is room for difference of opinion as to the interpretation of characters No 4 and 5 in the following table the remainder are statements of fact, and do not introduce the personal factor at all

TABLE 1

RELATIONSHIP OF THE DIPNOI TO THE AMPHIBIA

The following dipnoan characters resemble the same characters —	In the Amphibia	**In the bony Fishes**	**In the Elasmobranchs**	**In None more than others**
(1) The nearly complete cartilaginous nature of the skull	+		+	
(2) The internal opening into the otocrane (Lateral cranial fenestra)		+		
(3) The autostylic and monimostylic suspension	+			
(4) The nasal capsule	+			
(5) The dermal roof pattern				+
(6) The form of the frontal bone.	+			
(7) The form of the Squamosal bone	+			
(8) The form of the fore brain	+			
(9) The possession of internal nares	+			
(10) The form of the heart	+			
(11) The arterial system	+			
(12) The venous system	+			
(13) The fins				+
(14) The form and function of the air bladder	+			
(15) The structure and position of the glottis	+			
(16) The possession of an epiglottis	+			
(17) The possession of a true pelvic girdle	+			
(18) The mating call of the male	+			
(19) The body fluid	+			
(20) The cytological character of every tissue in the body	+			
(21) The form of the body				+
(22) The mode of swimming	+			
(23) The bones of the palate.				+
(24) The character of the scales				+
(25) The Cav 1 Muscle			+	
(26) The Cav 2 Muscle			+	
(27) The M interhyoideus			+	
(28) The M retractor mandibulae	+			
(29) The Mm interbranchiales	+			
(30) The Mm. levatores arcuum branchialium			+	

The following dipnoan characters resemble the same characters:—	In the Amphibia.	In the bony Fishes	In the Elasmobranchs	In None more than others.
(31) The M. cucullaris.			+	
(32) The Mm. subarcuales.		+		
(33) The M. constrictor pharyngei				+
(34) The M coracomandibularis.			+	
(35) The M coracobranchiales.			+	
(36) The M pterygoideus	+			
(37) The M quadratomandibularis	+			
(38) The general course of development	+			
(39) The mode of the development of the external form.	+			
(40) The manner of the development of the two-chambered auricle	+			
(41) The manner of the development of the amphibian characters in the arterial system	+			
(42) The manner of the development of the amphibian characters in the venous system	+			
(43) The development of the cerebral hemispheres	+			
(44) The early form of the chondrocranium	+			
(45) The development of the buccal cavity	+			
(46) The form of pituitary involution	+			
(47) The development of the flask glands	+			
(48 The development of the cement organs	+			
(49) The history of the palatoquadrate	+			
(50) The development of the M cucullaris		+		
(51) The development of the M retractor mandibulae	+			
(52) The development of the other muscles of the head			+	
(53) The development of outgrowths from the ductus endolymphaticus of the otocyst	+			
(54) The cytology of all the embryonic tissues	+			
(55) The development of true external gills	+			
(56) The act of copulation	+		+	
(57) The fact that the newly hatched young must be permitted to rest with the mouth out of water or they will drown	+			

THE EVOLUTION OF THE TETRAPOD LIMBS.

Beyond doubt, the tetrapod limb has been evolved from some form of fin. The palaeontologists, with their view largely directed by the finger-posts of the bone-paved road they travel, have devoted their contributions to the attempt to decide what is the most likely way in which the bony segments of such fins as those of *Sauripterus* and *Eusthenopteron* may have rearranged themselves into the primitive limb pattern, such as that of *Eryops*

Gregory (1935), and Romer and Byrne (1931), have given consideration to the effect of the attached muscles upon the rotation of the limb, but, so far as I am aware, no evidence has been produced by the palaeontologists that the musculature of the fin types selected as precursory to the limb type, was arranged segmentally along the length of the fin. In the living Crossopterygian *Polypterus*, and probably also in *Latimeria*, there is no such segmental arrangement of the muscle. In *Neoceratodus*, however, the muscle extends along the fins in a series of segments, in such wise as to permit of the differential movement of the segments of the fin upon one another (Fig. 8). It seems obvious that some such arrangement as this was essential as a prerequisite to the development of a jointed limb. The fins of the Dipnoi were of an extremely generalised type, such as may be imagined

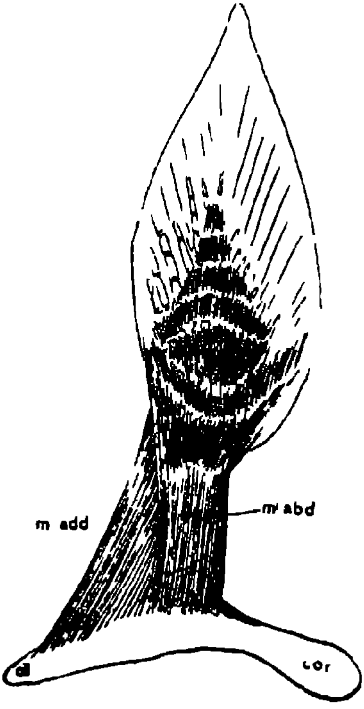


Fig. 8—The Muscles of the Pectoral Fin of Epiceratodus An external view of the superficial muscles. It will be noted that the superficial fasciculi extend across more than one joint but that, proximally, their deep portions extend across only one joint. The skeleton is shown in dotted lines.

to have been capable of variation, under the influence of this differential supply of muscles, and to have been capable of yielding, amongst these variations, the one which proved to be the starting point of the tetrapod limb.

Of course, this is not evidence that the tetrapod limb was derived from an archipterygium, but it must at least be conceded that the Dipnoi certainly possessed the one mechanical kinetic factor necessary for the evolution of the jointed limb.

The fact that *Neoceratodus* uses the pectoral limb to crawl clumsily out on to sloping rock to bask, is not evidence that it was used in the one way which would seem to have been most important to the production of a limb. *Periophthalmus* and a large number of the Gobiadae use the pectoral limbs in this manner a long way more efficiently than the Dipnoan does.

I have illustrated a dissection of the muscles of the fin of *Neoceratodus* which depicts the segmental arrangement of the muscles, and also the cartilaginous skeleton of the fin. I have not attempted to present drawings of hypothetical modifications of this fin, but it is obvious that its generalised form would permit changes to fit almost any series of modifications culminating in a primitive limb.

Conclusion

The natural classification of the vertebrate has been attempted by so many well-qualified men that to present still another classification calls, perhaps, for some justification.

It may be said of all recent attempts that they are based upon incomplete surveys of the facts which should be passed in review, and the present suffers from the same shortcoming. This is probably unavoidable. No one of us can possibly make himself sufficiently familiar with all the facts to undertake their evaluation himself. On the other hand it is submitted that an attempt to interpret the facts observed in a restricted field, but including all the vertebrate groups, by one who has devoted many years to the examination of those facts with that object in view, may be expected to advance the solution of the problem a little.

The field selected is the head and neck. During the past forty-odd years, the development and the anatomy of the head and neck of a very wide variety of representatives of every vertebrate group has been studied by the writer. In the course of that work it has appeared that too often investigators have accounted for similarities by assuming that they were coincidental or mere parallelisms, analogies, and not homologies, and so dismissed them.

The peculiar mixed characters of the Holocephali and the Sturgeon-like Chondrostei provide examples.

In A and B of diagram I below, characters 1 to 7 are outstandingly elasmobranchian, whilst characters 8 to 13 are outstandingly teleostoman. It can hardly be a coincidence that both the Chondrostei and the Holocephali combine so many of these characteristics. It seems that the only reasonable interpretation of the facts is that these 13 characteristics were present, actually or potentially, in the common ancestor of all four groups.

It is suggested that if these four groups were represented in numerical equality in the modern fauna they would all have been given equal rank and that the relegation of the two smaller to subgroups was simply the result of their numerical inferiority and is not justified by their structure

This concept permits the visualising of four distinct lines of differentiation at the dawn of the true fish epoch The Plagiostoman the Holocephalan the Chondrostean and the Teleostoman Thus we have four starting points for the evolution of the modern vertebrates

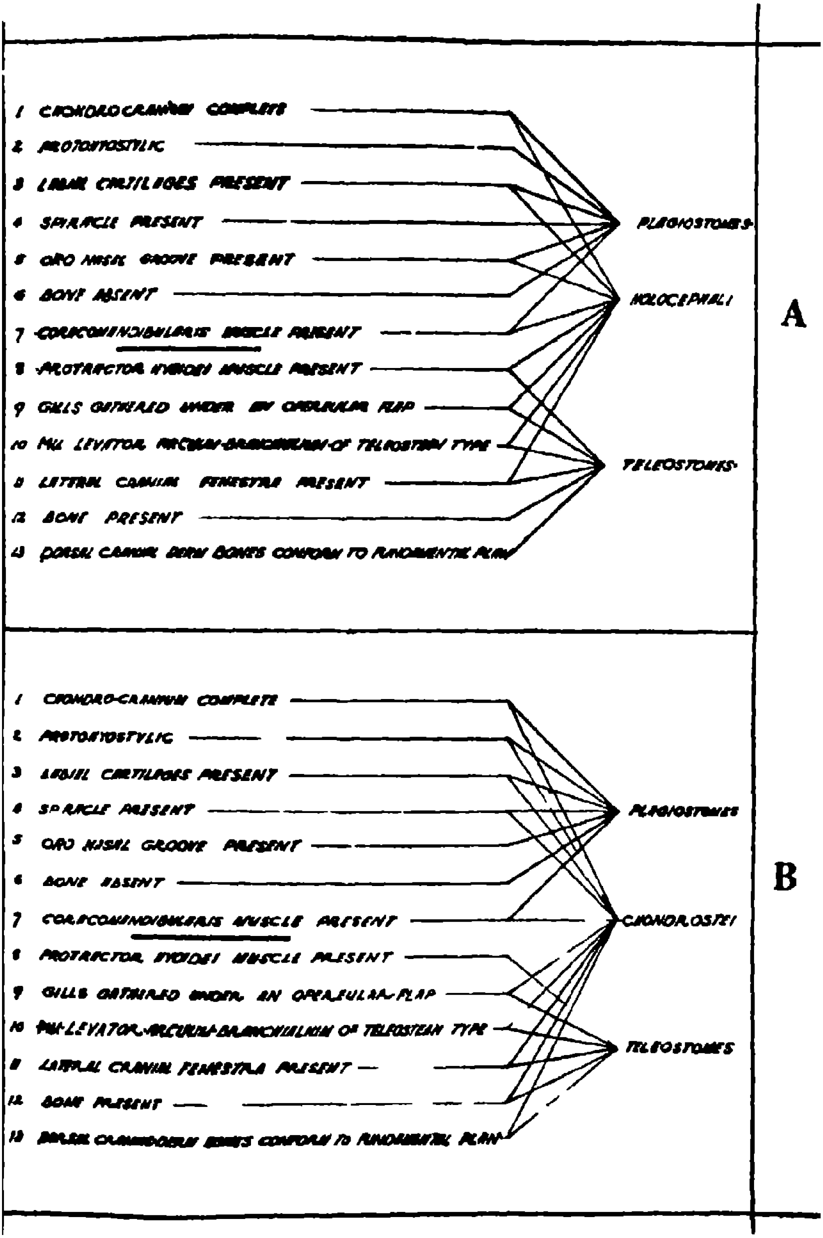
If however we turn to the geological record we find a group of Elasmobranchs the Acanthodei which seems to combine all the characters of the Chondrostei and Teleostomi and we are enabled to reduce our stem type to three and all three are Elasmobranchs The plagiostoman root form presents only the outstanding characteristics of the modern Plagiostomes omitting the Holocephali with their autostylic suspension and teleostoman type of branchial arrangement and opercular covering The branchial arrangement of the Holocephali is undoubtedly an acanthodian feature this suggests that the two groups are differential forms of a common ancestor

Therefore it is permissible to suppose that from some generalised fish form two main lines of evolution took definite form The one was the Elasmobranchian In this a primitive hyostylic suspension was retained the gill clefts were left exposed and the power to develop bone was more or less completely lost

In the second group the gills were collected under an operculum and the power to form bone was retained and improved upon In this group two main lines of change or specialisation soon manifested themselves In the one a modification of the hyostolic suspension was perfected in the other fibrous attachments of the palatoquadrate arch to the cranium posteriorly were converted into cartilaginous and finally bony unions and then articulations or fusions These two are of course the Acanthodian and the Holocephalan The Acanthodian root in turn gave rise to two different stocks One of these the Chondrostean had inherited strongly the primitive hyostylic suspensorial tendency and combined this with the other characters of the Acanthodei The other the Teleostoman stock however perfected the modified hyostylic mode of suspension

Turning finally to the Holocephalan stock we find ourselves in the presence of the most interesting combination of root stock characters in the series To begin with we find the Elasmobranchian specialisations very complete cartilaginous cranium and absence of bone next we have the acanthodian type of branchial skeleton with its operculum and finally we find Tetrapod suspension of the palatoquadrate without the utilisation of the hyoid

A comprehensive review of the vertebrate cranium reveals that invariably it commences as a fenestrated basket and sooner or later it is completed alternatively by cartilage or bone There is little doubt that cartilage is the more primitive tissue of the two Therefore whilst it is probably correct to regard the absence of bone in the modern Elasmobranchs as a specialisation in that there has been a complete loss of bone as a cranial building tissue the entirely cartilaginous cranium is fundamentally a primitive condition It is in this


1 CHONDROCRANIUM COMPLETE
2 PROTOHYOSTYLIC
3 LABIAL CARTILAGES PRESENT
4 SPIRACLE PRESENT
5 ORO NASAL GROOVE PRESENT
6 BONE ABSENT
7 CORACOMANDIBULARIS MUSCLE PRESENT
8 PROTRACTOR HYOIDEI MUSCLE PRESENT
9 GILLS GATHERED UNDER AN OPERCULAR FLAP
10 MU LEVATOR ARCUUM BRANCHIALIUM OF TELEOSTEAN TYPE
11 LATERAL CRANIAL FENESTRA PRESENT
12 BONE PRESENT
13 DORSAL CRANIAL DERM BONES CONFORM TO FUNDAMENTAL PLAN
PLAGIOSTOMES
HOLOCEPHALI
TELEOSTOMES
A
1 CHONDRO-CRANIUM COMPLETE
2 PROTOHYOSTYLIC
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4 SPIRACLE PRESENT
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PLAGIOSTOMES
CHONDROSTEI
TELEOSTOMES
B

Diagram I A diagram designed to show the culmination of different root stock characters in the Holocephali and in the Sturgeon like Chondrostei light that we should regard the cartilaginous cranium of the modern Holocephali. The absence of bone, however, is again a specialisation (comparable especially to the almost complete absence observed in Polyodon and Scaphyrhynchus) because the mesozooic Holocephali had more or fewer dermal bony plates related to the cranium. These modern members of the Holocephali are, of course, to be regarded as reflecting the general constitution of the root from which the Tetrapods have been evolved, and must also be deemed to have, themselves, departed in important particulars from that stock.

The first known definite tetrapod advance from the holocephalon stock is presented by the Dipnoi. Here we have a primitive Amphibian which retains a few very definitely "fish" characters. The outstanding resemblances to the Holocephali are the autostylic suspension, the lateral cranial fenestra (the wide opening into the otocrane from the neurocrane) and the branchial basket protected by its operculum.

It cannot, of course, be argued that the Dipnoi were themselves ancestral to the Tetrapods, but it should be clear from the tabulation of their tetrapod characters that they had advanced so far ahead of the Crossopterygians along the road to the Tetrapods that they cannot be regarded as having been derived from those fish. But, at the same time, the survival of the labial cartilages functioning as labial jaws in the Anura is such clear evidence of community of origin with the fishes that we must conclude they were both evolved from some earlier generalised form.

In diagram II I have made use of the term "osteichtys" for this generalised fish root-stock, and I have derived from it the Holocephali on the one hand and the Acanthodei on the other. From the Acanthodei, I derive the Chondrostei, which are to be regarded as a terminal type, and the Crossopterygii, which are to be regarded as the root-stock for all the rest of the bony fishes. From the Holocephalon root-stock I derive the Tetrapods.

Almost from their first appearance the Amphibians, which preceded all other Tetrapods in the Geological record, present themselves in three very distinct types, the Dipnoi, the Embolomeri, and the Labyrinthodont Amphibians. These may be interpreted as three divergent stocks which have evolved from the Holocephalon stem. The Dipnoi must be regarded as a persistent terminal group.

The Embolomeri and Ichthyostegidae may be united under the designation of Sauramphibia, to indicate that they must be regarded as the root-stock of the Saurians and higher Tetrapods generally, whilst the remainder may be designated Euamphibia. These last are all characterised by the retention of the undivided parasphenoid bone of the Fishes and are represented in the modern fauna by the Anura, Caecillia, and Urodela.

The Dipnoi probably are more closely related to the Sauramphibia than to others (Vide quotation from Elliott Smith, p. 127). Their exceedingly simple palate presents us with the simplest form of the divided parasphenoid bone. The deletion of most of the other bones of the upper jaw and palate must be regarded as the outstanding specialisation of this form of the primitive amphibian stock. The loss of bones is, in general, not phylogenetically significant; it is the form, relation to one another and to the neurocranium, and the mode of development of the bones which are developed that reflect phylogenetic influence. The absence of the bones from the Dipnoan palate must be interpreted by one of two ways. Either the Dipnoi are so primitive that they come from ancestral stock in which palatal bones were as yet not developed, or they have lost all but a few of those bones.

Unfortunately, which of these interpretations we shall adopt must be decided by the personal equation. We have as yet no definite evidence on which to found a perfectly sound argument.

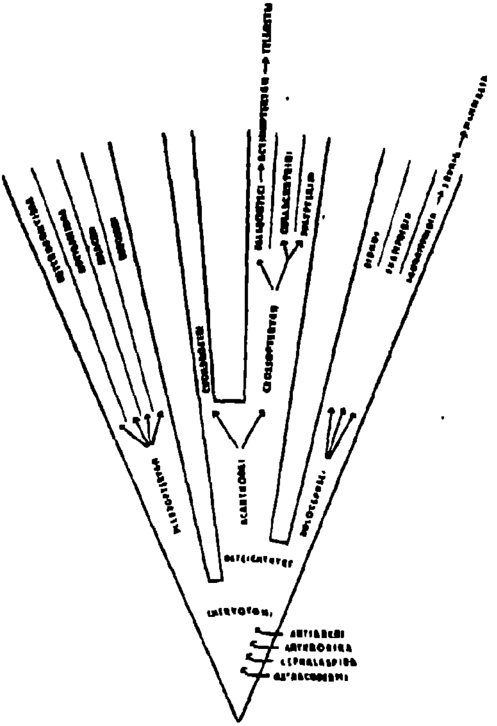

Diagram II.—A diagrammatic presentation of a natural classification of the Vertebrates.

It is a peculiar fact that the palaeontologists have either completely neglected the parasphenoid, commonly the largest contributor to the middle region of the palate in the fishes, or have been content to assume that an indefinite area of the basis cranii and a presphenoidal spur represented the bone, in their comparison of the Fish and primitive Tetrapod palates.

I have for long argued that the parasphenoid bones, so large and well-developed on the basis cranii of all fishes and modern Amphibians, is represented by the pterygoid bone in the Sauramphibia, the Dipnoi, and the rest of the Tetrapods. I have recently demonstrated, I believe irrefutably, that there is no parasphenoidal ossification on the base of the cranium in recent Sauria (Kesteven, 1940). It was also demonstrated (Kesteven, 1941, 1942) that the so-called parasphenoidal rostrum in the Avian skull is a cartilage bone and a true presphenoidal ossification.

The intrusion of the personal factor is unavoidable; it would be a weakness to try and disguise it, therefore — I find it difficult to believe that so important a bone in the ancestral forms should have no representation in the modern higher tetrapods. Especially, I find it difficult to understand how the parasphenoid bone of the Fishes can have been partly replaced by two *new* ossifications in the Dipnoi. Beyond question the posterior portions of the two palatopterygoid bones in the Dipnoi occupy, together, the exact position of the lateral wings of the parasphenoid of the fishes. I must continue to regard them as being the antero-lateral portions of that same bone, which has been divided into three When first it was suggested (Kesteven, 1916) that the parasphenoid had persisted in two halves in the higher vertebrate, the suggestion that a single bone in lower might be homologous with paired bones in higher vertebrata was novel. Later, various observers thought to record the development of this bone on the base of various Saurians, mistaking "extraperichondral ossification" (Kesteven, 1942 A. p. 224) for membrane bone Recently de Beer (1936), apparently without being aware of my earlier suggestion, proposed that the pterygoid of Ornithorhynchus be recognised as the lateral wings of the parasphenoid bone, and later de Beer (1937) extends this idea by suggesting that the dorsal component of the mammalian pterygoid is the homologue of the same lateral wing of the parasphenoid.

Returning to the question as to how we shall regard the paucity of bones in the Dipnoan palate If the palatopterygoid bones in that palate are to be regarded as the advanced, tetrapod form of the parasphenoid bone, it appears to follow that we must conclude that the paucity of other bones is the result of loss, and not of primitive absence.

Final conclusions are, of course, presented in the last diagram.

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Bonython, C W, B Sc, 22 Northcote-terrace Gilberton, South Australia	1945
Gault, E L, M A, M B, B S, 2 Collins-street, Melbourne, C 1	1899
Osborne, Emeritus Prof W A, M B, B Ch, D Sc "The Hall," Kangaroo Ground, Victoria	1910
Selby, G W, Glenbrook-avenue, Malvern S E 5	1889
Skeats, Emeritus Prof E W, D Sc, A R C Sc, F G S, 27 Kensington-road, South Yarra, S E 1	1905
Summers, Dr H S, 1 Winson Green-road, Canterbury, E 7	1902

ORDINARY MEMBERS

Agar, Prof W E, M A, D Sc F R S University, Carlton, N 3	1920
Anderson, George, M A, LLM, M Com, 30 Lansell-road, Toorak, S E 2	1924
Anderson, V G, 360 Collins street Melbourne, C 1	1943
Baragwanath, W, Geological Survey Department Treasury Gardens, East Melbourne, C 2	1922
Barker, Prof A F, M Sc, 10 Pasadena Mansions, St Kilda-road, Melbourne, S C 2	1940
Barrett, A O, 1 Queen-street, Melbourne C 1	1908
Blackburn, Maurice, M Sc, Zoology Department University N 3	1936
Brumwell, C Stanley, 11 Brougham-place, North Adelaide	1946
Boardman, W, M Sc, Zoology Department, University, N 3	1947
Buesst, T N M, 5 Torresdale-road Toorak, S E 2	1945
Bull, L B, D V Sc, Animal Health Research Laboratory, Parkville, N 2	1939
Campbell, H A M Cliveden Mansions, East Melbourne	1945
Casey, Dermot A, M C, F S A, 219 Orrong road, Toorak S E 2	1932
Cherry, Prof T M, B A, Ph D, University Carlton, N 3	1930
Clark, A M, M Sc, 9 Grattan-street Hawthorn, E 2	1940
Clark, G Lindesay, M C, B Sc, M M E c/o Gold Mines of Australia Ltd, P O Box 856K, Melbourne C 1	1931
Colliver, F S, 37 McCarron-parade, Essendon, W 5	1933
Coulson, A L, D Sc, D I C, F G S 324 Cotham-road, Kew E 4	1919
Cox, Leonard B, M D, B S, M R C P, 719 Toorak-road, Malvern S E 4	1946
Cudmore, F A, 12 Valley View-road East Malvern, S E 6	1920
Davis, John King, 35 Wills-street, Melbourne C 1	1920
Day, Arthur J, M B, B S, 227 Toorak-road, South Yarra S E 1	1946
Devine, Sir Hugh 57 Collins-street, C 1	1946
Devine, John, M S, F R C S, 57 Collins street, C 1	1945
Drummond, F H, Ph D, B Sc, University, Carlton, N 3	1933
Dunn, J A D Sc, D I C, F N I, F G S, 417 Glenferrie-road, Hawthorn, E 2	1946

Dyason, E C, B Sc, B M E, 92 Queen-street, Melbourne, C 1	1919
Edwards, A B, D Sc, Ph D, D I C, Geology School, University, Carlton, N 3	1930
Esserman, N A, B Sc, A Inst P, National Standards Laboratory, University Grounds, Sydney	1923
Fitts, Dr Clive, M D, 14 Parliament-place, C 2	1945
Gepp, Sir Herbert W, Box 1643, G P O, Melbourne	1926
Gill, Rev, E D B A, B D 26 Winifred-street, Essendon, W 5	1938
Gray, Dr K Washington, c/o Australasian Petroleum Co., 37 Queen-street, Melbourne, C 1	1946
Grice, J Hugh, 'Highfield," Lilydale	1938
Grimwade W Russell C B E, B Sc, 342 Flinders-lane, Melbourne, C 1	1912
Hartmann S 628 St Kilda-road, S C 3	1946
Hartung, Prof E J, D Sc University, Carlton, N 3	1923
Hills Prof E S, D Sc, Ph D, Geology School University, Carlton, N 3	1928
Hordern A, 242 Walsh-street, South Yarra, S E 1	1940
Hudson T J 42 Kensington-road, South Yarra	1945
Jack R Lockhart B E, D Sc, F G S, 54 Clowes St, South Yarra, S E 1	1931
James, A, B A D Sc, 23 Bayview-crescent, Black Rock, S 9	1917
Jutson J T D Sc, LL B, 'Darlington," 9 Ivanhoe-parade, Ivanhoe, N 21	1902
Kannuluik, W G D Sc, Physics Department, University, N 3	1946
Keble R A, National Museum Melbourne, C 1	1911
Kesteven, H Leighton, D Sc, M D, The Hospital, Cooktown, Queensland	1945
Kimpton V Y, 16 Lansell road, Toorak S E 2	1946
Lang, P S B Agr Sc School of Agriculture University, N 3	1938
Latham L S, M A, M B B S 33 Collins street, C 1	1946
Leeper, G W, M Sc Chemistry School, University Carlton, N 3	1931
Lewis Essington C H, c/o Broken Hill Pty Ltd, 422 Little Collins-street, C 1	1945
Lewis, J M, D D Sc, 'Whitethorns,' Boundary-road, Burwood, E 13	1921
MacCallum Prof Peter M C, M A, M Sc, M B, Ch B, D P H, University, Carlton N 3	1925
McPherson, Sir Clive C B E, 216 Domain-road South Yarra, S E 1	1946
Martin Prof L H, Ph D, F Inst P, University, N 3	1945
Medley, J D G M A University N 3	1945
Miller, E Studley, 220 Kooyong-road, Toorak S E 2	1921
Miller, Leo F "Moonga," Power-avenue, Malvern S E 4	1920
Millikan C R M Agr Sc Plant Research Laboratory, Swan-street, Burnley E 1	1941
Montgomery, J N, c/o A'asian Petroleum Co Pty Ltd, 37 Queen-street, C 1	1945
Moore K Byron, 11 Mona place South Yarra, S E 1	1945
Morrison, P Crosbie, M Sc 44-74 Flinders-street, C 1	1938
Murdoch, Sir Keith Albany-road, Toorak S E 2	1945
Nicholas, Geo R, 48 Lansell road, Toorak, S E 2	1934
Olsen C O B A Dip Ed 46 Clendon-road, Toorak, S E 2	1945
Orr, Dr R Graeme M A B Ch 11 Maple grove, Toorak, S E 2	1935
Orr Dr W F 11 Maple-grove Toorak, S E 2	1932
Parr, W J 17 Bokhara road Caulfield S E 8	1927
Patton, R T D Sc, M F (Harv), D I C, Hartley-avenue, Caulfield, S E 8	1922
Pescott, R T M National Museum Melbourne, C 1	1944
Piesse E L, 43 Sackville-street, Kew E 4	1921
Pitt E R B A F L A, "Summerlea" 78 Riversdale-road, Hawthorn E 2	1946
Pittman H A J, B A, B Sc Agr (Hons), Dip Ed, Plant Research Laboratory Swan-street, Burnley, E 1	1942
Priestley R E, M A D Sc, University, Birmingham	1935
Quayle E T, B A, 27 Collins-street, Essendon, W 5	1920
Reid, J S 498 Punt-road, South Yarra, S E 1	1924

Richardson, A E V, C M G, M A, D Sc Council for Scientific and Industrial Research, 314 Albert-street East Melbourne C 2	1938
Rivett, Sir David K C M G M A D Sc Council for Scientific and Industrial Research 314 Albert street East Melbourne C 2	1911
Rogers, J Stanley, M C B A M Sc F Inst P University Carlton N 3	1924
Rose, F G G, Division of Regional Planning Post War Reconstruction Canberra	1944
Rubbo Prof S D Ph D Dip Bact (London) B Sc M P S (Syd) M B B S (Melb) University N 3	1946
Sayce E L, B Sc A Inst P Research Laboratories Maribyrnong W 3	1924
Sewell Sir Sidney V 12 Collins street C 1	1936
Smith Dr Hubert R 59 Collins street C 1	1945
Spicer P O c/o Imperial Chemical Industries 380 Collins street C 1	1946
Stillwell F L, D Sc 44 Elphin grove Hawthorn E 2	1910
Stokes Dr H Lawrence 232 Kooyong road Toorak S E 2	1945
Stokes Russell N 2 Torresdale road Toorak S E 2	1945
Sullivan W, 326 Exhibition street Melbourne C 1	1943
Sunderland, Professor S D Sc M B B S University Carlton N 3	1945
Tattam C M Ph D D Sc D I C, Geology Department University N 3	
Teichert C D Sc Geology Department University Carlton N 3	1945
Thomas D E D Sc Mines Department Melbourne C 2	1929
Thomas D J M D 81 Collins street Melbourne C 1	1924
Tiegs Assoc Prof O W D Sc F R S University Carlton N 3	1925
Turner Professor J S M A Ph D M Sc University Carlton N 3	1938
Vail Col L E E D 26 Chaucer street Canterbury E 7	1939
Wadham Prof S M M A Agr Dip, University Carlton N 3	1932
Warren H N, Central Weather Bureau Box 1289 K G P O Melbourne	1946
Weigall Dr Gerald, 34 Avoca street South Yarra S E 1	1945
Wettenhall, Dr Roland R Aberfeldie 557 Toorak road S E 2	1938
White Dr A E Rowden 14 Parliament place Melbourne C 2	1938
Withers R B M Sc Dip F I Food Preservation Research Laboratories Private Bag Homebush N S W	1926
Woodruff Professor H A M R C S L R C P M R C V S 84 Fellows street Kew E 4	1913
Woolnough W G D Sc 12A Louvain 24 Leopold street South Yarra S E 1	
Wright Prof R D D Sc M B M S F R A C S F R A C P University Carlton N 3	1941
Zwar Dr B T 2 Hamilton road Malvern S E 4	1946

COUNTRY MEMBERS

Adams H E Danedite Weerite Vic	1945
Brown W Bureau of Mineral Resources 485 Bourke street Melbourne C 1	1946
Buley J V B Sc c/o Golden Plateau N L Cracow Queensland	1946
Burston Gerald Koorana Euroa Vic	1945
Caddy Dr Arnold Chandpara Tylden Vic	1924
Caldwell, J J Geological Survey Office Bendigo Vic	1930
Currie Mrs Ian Seven Oaks Euroa	1941
Felstead Dr J G R Box 30 Horsham	1945
Glaessner M F Ph D Australasian Petroleum Co Pty Ltd 37 Queen street Melbourne C 1	1939
Gloe C State Rivers and Water Supply Dept 100 Exhibition street C 1	1944
Harris, W J, B A D Sc Box 34 Warragul Vic	1914
Hill Dr Dorothy Geology Dept University Brisbane Queensland	1939
Hope G B, B M E Carrical Hermitage road Newtown Geelong Vic	1918

Jenkin, J. J., 35 Marley-street, Sale	1945
Knight, J. L., B.Sc., c/oMines Department, Treasury Gardens, C.1	1944
Mack, G., B.Sc., Queensland Museum, Brisbane, Queensland	1943
Mackenzie, H. P., Engr. Commr., R.N. (Ret.), Trawalla, Vic.	1924
Mann, S. F., Caramut, Vic.	1922
Martin, Miss Gwen J., B.Sc., High School, Ararat	1946
Middleton, Dr. F. G., Nhill, Victoria	1946
Payne, T. E. Neville, "Woodburn," Kilmore, Vic.	1945
Quayle, D. S., 183 Greville-street, Prahran	1939
Trebilcock, Captain R. E., M.C., Wellington-street, Kerang, Vic.	1921
White, R. A., B.Sc., School of Mines, Bendigo, Vic.	1918
Yates, H., School of Mines, Ballarat, Vic.	1943

ASSOCIATES.

Adams, L., 111 Ferrars-street, South Melbourne, S.E.5	1946
Aitken, Miss Y., M.Agr.Sc., School of Agriculture, University, Carlton, N.3	1936
Alderman, A. R., M.Sc., Ph.D., F.G.S., Box 4331, G.P.O., Melbourne, C.1	1942
Bage, Miss F., M.Sc., O.B.E., Grove-crescent, Toowong, Brisbane, S.W.1, Qld	1906
Baker, A. A., 52 Carlisle-street, Preston, N.18	1946
Baker, G., M.Sc., Geology Department, University, N.3	1935
Bottoms, E. A., 68 Robinsons-road, Hawthorn, E.2	1943
Brazenor, C. W., National Museum, Russell-street, Melbourne, C.1	1931
Broadhurst, E., M.Sc., 457 St. Kilda-road, Melbourne, S.C.2	1930
Buckle, G., B.Sc., 58 Millswyn-street, South Yarra, S.E.1	1945
Butcher, A. D., M.Sc., Fisheries & Game Dept., 605 Flinders-street, C.1	1936
Butler, L. S. G., No. 3 Los Angeles Court, St. Kilda, S.2	1929
Canavan, F., B.Sc., c/o Broken Hill Pty. Ltd., 422 Little Collins-street, Melbourne	1936
Carter, A. A. C., "Fairholm," Threadneedle-street, Balwyn, E.8	1927
Carter, A. N., Box 2, "St. Ronan," 10 Berkeley-street, Hawthorn, E.2	1947
Chapman, W. D., Brigadier, M.C.E., "Hellas," Stawell-street, Kew, E.4	1927
Chapple, Rev. E. H., The Manse, Warrigal-road, Oakleigh, S.E.12	1919
Chatterjee, P. K., c/o Geological Survey of India, 27 Chowringhee, Calcutta, India	1946
Clinton, H. F., "Whitehall," 20 Bank-place, C.1	1920
Cochrane, G. W., B.Sc., Queens College, Carlton, N.3	1945
Collins, A. C., 3 Lawrence-street, Newtown, Geelong	1928
Condon, M. A., B.Sc., 14 Blyth-street, Altona, W.18	1937
Cook, G. A., M.Sc., B.M.E., 58 Kooyongkoot-road, Hawthorn, E.2	1919
Cookson, Miss I. C., D.Sc., 154 Power-street, Hawthorn, E.2	1916
Coulson, A., M.Sc., Bridport-street, Daylesford	1929
Cowen, Miss Margot E. H., B.Agr.Sc., 2 Leaburn-avenue, S.E.7	1936
Crespin, Miss I., B.A., Bureau of Mineral Resources, Melbourne Buildings, Canberra, A.C.T.	1919
Crohn, P. W., B.Sc., Geology Dept., University, N.3	1946
Croll, I. C. H., M.Sc., 53 The Boulevard, Hawthorn, E.2	1934
Croll, R. D., B.Agr.Sc., 18 Russell-street, Camberwell, E.6	1940
Dadswell, Mrs. Inez W., M.Sc., 72 Florizel-street, Burwood, E.13	1939
Deane, Cedric, 461 St. Kilda-road, Melbourne, S.C.2	1923
Deshpandé, B. G., c/o Geological Survey of India, 27 Chowringhee, Calcutta, India	1946
Dickinson, Miss Jill, B.Sc., Forests Commission, Treasury Gardens	1944
Down, Mrs. Mary R., B.Agr.Sc., 35 Durham-street, Heidelberg, N.22	1942
Dunn, R. A., A.A.A., A.A.I.S., 57 Oakleigh-road, Carnegie, S.E.9	1946
Edwards, G. R., B.Sc., High School, Portland	1937
Elford, F. G., B.Sc., B.Ed., 76 New-street, Brighton, S.5	1929
Elford, H. S., B.E., c/o Tait Publishing Co., 349 Collins-street, Melbourne, C.1	1934
Fawcett, Miss Stella G. M., M.Sc., Box 54, P.O., Omeo	1937
Ferguson, W. H., 37 Brinsley-road, E. Camberwell, E.6	1894

Forster, H. C., B.Agr.Sc., Ph.D., 6 Glendene-avenue, Kew, E.4	1938
Frostick, A. C., 9 Pentland-street, N. Williamstown, W.16	1933
Gabriel, C. J., 293 Victoria-street, Abbotsford, N.9	1922
Gaskin, A. J., M.Sc., 6 Olive-street, E. Malvern, S.E.5	1941
Gillespie, J. M., M.Sc., 22A Mercer-road, Malvern, S.E.3	1941
Gladwell, R. A., 79 Cochrane-street, Elsternwick, S.4	1938
Gordon, Alan, B.Sc., c/o C.S.I.R., Yarra Bank-road, South Melbourne, S.C.4	1938
Goudie, A. G., B.Agr.Sc., Department of Agriculture, Melbourne	1941
Grieve, Brian J., M.Sc., Ph.D., D.I.C., Botany School, University, N.3	1929
Gunson, Miss Mary, M.Sc., Zoology Dept., University, N.3	1944
Hague, A. F. M. M., c/o Geological Survey of India, 27 Chowringhee, Calcutta, India	1946
Hanks, W., 7 Lake-grove, Coburg, N.14	1930
Hardy, A. D., 24 Studley-avenue, Kew, E.4	1903
Hauser, H. B., M.Sc., Geology School, University, Carlton, N.3	1919
Head, W. C. E., Campbell-street, Nhill	1931
Heysen, Mrs. D., P.O., Box 10, Kalangadoo, South Australia	1935
Hill, R. D., D.Sc., F.Inst.P., Physics Dept., University, N.3	1946
Hogan, T. W., 22 Cornell-street, Burwood, E.13	1947
Holland, R. A., 526 Toorak-road, Toorak, S.E.2	1931
Holmes, W. M., M.A., B.Sc., 1 Balmoral-avenue, Kew, E.4	1913
Honman, C. S., B.M.E., 3 Fairy-street, Ivanhoe, N.21	1934
Hopper, V. D., M.Sc., F.Inst.P., Physics Dept., University, N.3	1946
Hutchinson, R. C., B.Sc., Dept. of Agriculture, Rabaul	1939
Jack, A. K., M.Sc., 49 Aroona-road, Caulfield, S.E.7	1913
Jacob, Dr. J., c/o Geological Survey of India, 27 Chowringhee, Calcutta, India	1946
Jacobson, R., M.Sc., 41 Thanet-street, Malvern, S.E.4	1937
Jessep, A. W., B.Sc., M.Agr.Sc., Botanical Gardens, Sth. Yarra, S.E.1	1927
Jona, J. Leon, M.D., M.S., D.Sc., Lister House, 61 Collins-street, Melbourne, C.1	1914
Kenny, J. P. L., B.C.E., Mines Department, Public Offices, C.2	1942
Kilvington, T., M.Sc., Physiology Department, University, N.3	1938
Langham, Miss Beryl, B.Sc., 8 Myrtle-road, Hampton, S.7	1945
Law, P. G., M.Sc., Physics Dept., University, N.3	1946
McCance, D., M.Sc., 144 Gatehouse-street, Parkville, N.2	1931
McLennan, Assoc. Prof. Ethel, D.Sc., University, Carlton, N.3	1915
Macpherson, Miss J. Hope, B.Sc., National Museum, Melbourne	1940
Manning, N., 16 Fairmont-avenue, Camberwell, E.6	1940
Mather, W. B., B.Sc., c/o Zoology School, University, N.3	1946
Melhuish, T. D'A., M.Sc., c/o Elliots & Aust. Drug Pty. Ltd., Terry-street, Rozelle, N.S.W.	1919
Mitchell, A. W. L., B.Sc., 16 Keeron-street, Caulfield, S.E.8	1946
Mitchell, S. R., 22 Grosvenor-street, Abbotsford, N.9	1945
Morris, P. F., National Herbarium, South Yarra, S.E.1	1922
Moy, A. F., Melbourne Boys High School, Forrest Hill, South Yarra, S.E.1	1943
Mushin, Mrs. Rose, M.Sc., Bacteriology Dept., University, N.3	1940
Newman, B. W., B.Sc., Meteorological Bureau, Sydney	1927
Nye, E. E., College of Pharmacy, 360 Swanston-street, Melbourne, C.1	1932
Oke, C., 34 Bourke-street, Melbourne, C.1	1922
Osborne, N., 35 Dorrington-avenue, Glen Iris, S.E.6	1930
Pinches, Mrs. M., 8 Thomas-street, Brunswick, N.10	1943
Prentice, H. J., B.Sc., Strangways, Victoria	1936
Pretty, R. B., M.Sc., Technical School, Wonthaggi, Vic.	1922
Raff, Miss J. W., M.Sc., F.R.E.S., University, Carlton, N.3	1910
Richardson, Sidney S., 16 Brewster-street, Essendon, W.5	1923
Samson, H. R., B.Sc., 250 Grange-road, Ormond, S.E.9	1945
Scott, T. R., M.Sc., B.Ed., 27 Currajong-avenue, Camberwell, E.6	1934
Seeger, R. C., 56 Jenkins-street, Northcote, N.16	1946
Shaw, Dr. C. Gordon, 57 Clendon-road, Toorak, S.E.2	1931
Sherrard, Mrs. H. M., M.Sc., 43 Robertson-road, Centennial Park, N.S.W.	1918
Shipp, A., "Cangort," Canterbury-road, Heathmont	1946

Singleton, O P, 126 Anderson-street, South Yarra, S E 1	1943
Stach, L W, M Sc, 78 Herbert-street, Albert Park, S C 6 .	1932
Stubbs, G C, Plant Research Laboratory, Swan-street, Burnley, E 1	1943
Thomas, G A, B Sc, 115 Barkley-street, Mordialloc . ..	1944
Thomas, L A, B Sc, c/o Council for Scientific and Industrial Research, Stanthorpe, Queensland	1930
Trudinger, W 27 Gerald-street Murrumbeena, S E 9 ..	1918
Tubb, J A, M Sc, Fisheries Section C S I R, Cronulla, N S W	1936
Vasey, A J, B Agr Sc, Animal Health Laboratory, Parkville, N 2	1937
Vasey, G H, B C E, University Carlton, N 3	1936
Weigall Dr Gerald 34 Avoca-street South Yarra, S E 1 ..	1945
White Miss Lilian B Sc, 241 Domain-road, South Yarra, S E 1 .	1947
Wade, G C B Agr Sc Plant Research Laboratory Swan-street, Burnley E 1	1941
Whincup Mrs Sylvia, M Sc National Museum Russell-street, C 1	1942
Wilcock, A A B Sc B Ed Geology Dept University N 3	1934
Wood Prof G L, M A Litt D, University Carlton, N 3	1933
Woodburn Mrs Fenton, 21 Bayview-crescent Black Rock S 9	1930

Royal Society of Victoria.

ANNUAL REPORT OF THE COUNCIL FOR THE YEAR 1946

The President and Council present to members of the Society the Annual Report and Statement of Receipts and Expenditure for the year 1946. The following meetings of the Society were held:

March 14: Annual Meeting. The following office-bearers were elected: President, Captain J. K. Davis; Vice-Presidents, Major D. A. Casey, Professor J. S. Turner; Honorary Treasurer, Mr. W. J. Parr; Honorary Librarian, Mr. F. A. Cudmore; Honorary Secretary, Dr. F. L. Stillwell; Members of the Council, Professor E. W. Skeats, Professor S. M. Wadham, Professor R. D. Wright, Dr. R. T. Patton, Mr. P. Crosbie Morrison, Mr. W. Baragwanath.

The following members of Council continued in office Professor W. A. Osborne, Professor E. S. Hills, Dr. H. S. Summers, Associate Professor O. W. Teigs, Dr. J. S. Rogers, Professor L. H Martin.

The Annual Report and Financial Statement for 1945 were read and adopted.

At the close of the Annual Meeting an Ordinary Meeting was held. Lecture: "Magellan," by Captain J. K. Davis.

April 11: Lecture: "Radar," by Dr. E. G Bowen.

May 9· Lecture: "Brown Coal in Victoria," by Dr A B Edwards.

June 13: Papers: "A Fossil Crab from the Lakes Entrance Oil Shaft, Gippsland, Victoria," by Miss Irene Crespin "A New Trilobite from the Yeringian (Lower Devonian) Rocks of Kinglake, Victoria," by Rev. E. D. Gill "Decapod Crustacea (Callianassa) from the Eocene of Victoria," by Dr. M F. Glaessner.

July 11: Paper: "A Survey of Vegetable Matter in the Wool Clip of S.E. Australia," by Miss S. J. Church. Lecture· "The Discovery and Some Applications of X-Rays," by Dr. C. E. Eddy

August 8: Mr. R. T. M. Pescott was elected Honorary Treasurer, following the resignation of Mr. W. J. Parr owing to ill-health. Lecture: "Impressions of a Recent Visit to England and America," by John Devine.

September 12: Special General Meeting. The following alterations to the Laws of the Society were agreed to:—

1. That the words in Law 46, "1st of November in each year," be deleted and replaced by "1st March in the year following," and that the words, "November meeting," be deleted and replaced by "March meeting in the year following."

2. That the following new Law be inserted after Law 13 to define the duties of the Librarian: "The Librarian shall be responsible for the welfare and order of the Library. He shall catalogue the books received and see that they are correctly placed upon the shelves. He shall issue notices to members holding books overdue from the library. He shall acknowledge all donations of books, and, when necessary,

those received in exchange He shall check the index of volumes recently received and shall write for any volumes due to the Society He shall select the books for binding and shall recommend the books to be purchased for the Howitt Memorial Fund He shall bring all requests for exchange of publication before the Council and shall report any interruption of an agreed exchange He shall file a copy of all correspondence in connection with books and shall provide lists for the C S I R Catalogue of Periodicals

At the conclusion of the Special General Meeting an Ordinary Meeting was held Lecture Calendar Reform by Professor W A Osborne

October 10 Paper Late Quaternary Changes of Sea Level at Rottnest Island Western Australia by Dr C Teichert Lecture The Royal Society Empire Scientific Conference by Professor E S. Hills

November 14 Lecture The Cult of Humus — A Campaign against Fertiliser by Associate Professor G W Leeper

December 12 Papers A Review of the Palaeozoic Genus *Hercynella* with a Description of Three Species from the Yeringian (Lower Devonian) in Victoria, by Rev F D Gill The Origin of the Tetrapods by Dr H Leighton Kesteven Lecture Review of Progress in the Study and Utilization of Clays by A J Gaskin

The Use of the Society s Hall for Defence purposes by the Army Hiring Department under the National Security Regulations, terminated during the year A similar arrangement has been entered into with the Commonwealth Meteorological Bureau

During the year 18 members 4 country members and 19 associate members were elected The total membership of the Society on December 31 1946 was 253 consisting of 8 life members 100 members 29 country members and 116 associate members The total at December 31 1945 was 220

The Council deeply regrets the loss by death of one life member and one country member

James Andrew Kershaw died on February 16 aged 79 years He was born in Melbourne in 1866 and educated at the Alma Road State School and a grammar school East Street St Kilda He was appointed an assistant to the staff of the National Museum in 1883, and gave life long service to this institution He became Curator in 1900 and Director after the resignation of Sir Baldwin Spencer in 1929 After his retirement in 1931 he continued his association with the Museum as Honorary Curator of Zoology He took a prominent part in securing the permanent reservation of Wilson s Promontory as a sanctuary for the preservation of native fauna and flora and was Honorary Secretary of the Committee of Management from its inception in 1908 till 1946 From an early date he was a Fellow of the Royal Entomological Society of London and in 1927 was elected a Corresponding Member of the Zoological Society of London He was elected a member of this Society in 1900 and served on the Council from 1902 till 1935 He was President 1918 1919 Honorary Secretary 1920 23 Honorary Librarian 1924 1925 and a Trustee from 1922 until his death He contributed to the Proceedings in 1910 a paper on the Wombat *Phascolomys ursinus* Shaw from Flinders Island

William Crawford died on July 14 aged 69 years He was born at Newham, near Woodend and educated at the Newham State School After attending classes at the Working Men s College Melbourne he established himself in business as a plumber and builder at Gisborne His main recreation and relaxation took the form of long rambles, or motor cycle tours of the surrounding districts in pursuit of geological interests He thereby accumulated a knowledge of the local geology which was remarkable in its detail He was always willing to place this knowledge at the disposal of all who were interested and guide them over the district With Dr W J Harris as joint author, he contributed a paper to the Proceedings of this Society in 1921 on "The Relationships of the Sedimentary Rocks of the Gisborne District" In 1939 with Dr A P Edwards as joint author he contributed a paper on The Cainozoic Rocks of the Gisborne District He was elected a Country Member of the Society in 1920

The attendances at the Council Meetings were as follows Mr Baragwanath, 10 Captain Davis 10 Professor Skeats 10 Mr Cudmore 9, Mr Morrison 9 Dr Rogers 8 Dr Summers 8 Professor Turner 7 Mr Casey 6 Professor Hills 6 Dr Patton 6 Dr Stilwell 6, Associate Professor Tiegs 6 Professor Wadham 6 Professor Martin 5 Professor Osborne 5 Mr Parr 5 Professor Wright 5, Mr Pescott 4

During the year 2674 volumes and parts were added to the library This is more than double the number received for the preceding year and indicates a considerable measure of resumption of overseas exchanges which were interrupted by the War

Volume 57 of the Proceedings of the Society was issued in April The publication of this volume was assisted by a credit of £100 made available at the Government Printing Office by the State Government and by grants from the University Publications Fund towards the cost of publishing papers from the Science Departments of the University of Melbourne The Council desires to record its thanks to these bodies for this assistance Congestion of work at the Government Printing Office has caused long delays in the issue of the Proceedings

HONORARY TREASURER S REPORT

The financial position of the Society continues to be satisfactory The credit balance at the bank at December 31 1946 was £488/4/1 as against £302/4/5 at the end of the previous year It is pleasing to be able to report an increase in membership

The publication of the Proceedings is now eighteen months in arrears and on this account the cash balance is considerably larger than would otherwise be the case

Financial Statement for Year ending December 31 1946

RECEIPTS		
Balance in Bank at 1/1 46		£302 4 5
Subscriptions—		
Members	£162 15 6	
Associate Members	96 2 3	
Country Members	19 19 0	
Arrears paid up	59 6 6	
Advance Subscriptions	6 15 0	
		344 18 3
Rents—		
Commonwealth Government	£166 13 4	
Field Naturalists' Club	16 0 0	
Microscopical Society	11 0 0	
		193 13 4
Sale of Publications		18 5 11
Interest on Bonds		16 6 5
Grants and Donations—		
University of Melbourne	£88 7 0	
Danks Trust	10 0 0	
		98 7 0
Sundry Items		40 19 0
		£1 014 14 4

EXPENDITURE		
Printing—		
Volume 57	£296 13 2	
General	29 8 9	
Library	0 15 9	
		£326 17 8
Salaries—		
Assistant Secretary	£18 0 0	
Assistant Editor	20 0 0	
Assistant Librarian	8 0 0	
Hallkeeper	12 0 0	
Gardener	26 0 0	
		84 0 0
Light Water Gas		11 4 0
Telephone		13 5 1
Rates and Taxes		14 6 8
Insurance		6 15 0
Petty Cash		17 0 0
Postage		18 3 6
Repairs and Replacements		4 17 6
Meetings		11 1 4
Library		16 6 6
Stationery		0 12 6
Fire Brigade		1 0 0
Sundries		1 0 6
Balance in Bank at 31/12/46		488 4 1
		£1,014 14 4

R T M PESCOTT, *Hon Treasurer*

Audited and found correct,

February 28, 1947

G L WOOD } *Hon*
T M CHERRY } *Auditors*

SPECIAL FUNDS

HALL FUND

Balance at 1/1/46	£63	12	7	Balance at 31/12/46	£64	17	9
Interest to 31/5/46	1	5	2				
	£64	17	9		£64	17	9

LIFE MEMBERSHIP FUND

Balance at 1/1/46	£129	13	3	Balance at 31/12/46	£132	0	9
Interest to 31/5/46	2	7	6				
	£132	0	9		£132	0	9

HOWITT MEMORIAL FUND

Balance at 1/1/46	£98	9	6	Balance at 31/12/46	£106	5	1
Interest on Bond	5	16	3				
Savings Bank Interest to 31/5/46	1	19	4				
	£106	5	1		£106	5	1

T S HALL MEMORIAL FUND

Balance at 1/1/46	£72	14	7	Balance at 31/12/46	£74	3	5
Interest to 31/5/46	1	8	10				
	£74	3	5		£74	3	5

Accounts and Pass-books relating to each of the above Funds have been severally examined and found correct, and the Bank certificate of possessor of Bonds amounting to Five hundred pounds (£500), War Savings Certificates to the face value of Two hundred and fifty pounds (£250) and Fixed Deposit of Two hundred pounds (£200) have also been inspected.

G. L. WOOD } *Hon.*
T. M. CHERRY } *Auditors.*

R. T. M. PESCOTT, *Hon. Treasurer.*

February 28, 1947.

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